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DIGEST of
PROCEEDINGS OF THE
SECOND ANNUAL
MONTANA
BITUMINOUS CONFERENCE

HELD AT MANY GLACIER HOTEL
Glacier National Park
September 8th, 9th, & 10th

1936

MONTANA STATE HIGHWAY
COMMISSION

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The Second Annual

Montana Bituminous Conference

Many Glacier Hotel
Glacier National Park
September 8, 9, 10
1936

Montana
State Highway Commission

COMMITTEES

RECEPTION AND REGISTRATION

D. L. Cheney, Bituminous Engineer
Montana State Highway Commission

O. E. Cutting, Senior Assistant
Office Engineer,
Montana State Highway Commission

TRANSPORTATION

Guy J. Johnson, Division Engineer,
Montana State Highway Commission

A. G. Middleton, Division Engineer,
Montana State Highway Commission

S. B. Sanders, Resident Engineer,
Montana State Highway Commission

L. F. Schuknecht, Field Equipment Supt.
Montana State Highway Commission

PROGRAM

E. B. Donohue, Assistant State
Highway Engineer
Montana State Highway Commission

ENTERTAINMENT

R. H. Fletcher, Plans Engineer,
Montana State Highway Commission

J. F. Higgins, Accountant,
Montana State Highway Commission

Marion Jawort, Secretary,
Montana Contractors' Association

PROGRAM

Tuesday, September 8th

General Chairman,
D. A. McKinnon, State Highway Engineer,
Montana State Highway Commission

Registration—8:00-8:45

9:00

Meeting called to order by
D. A. McKinnon, General Chairman

9:15

Address of Welcome,
Hon. Elmer Holt, Governor of Montana

9:30

Welcome to Glacier National Park
E. T. Scoyen, Superintendent

9:45

Address—Dr. Harry J. McGregor,
Chairman, Montana State Highway Commission

10:00

Review of Analytical Engineering Methods and Research as applied to Bituminous Construction.

By Prof. L. D. Conkling,
Montana State College

10:45

Recess

11:00

Conference on Review of Analytical Engineering Methods and Research as applied to Bituminous Construction.

Conference Board:

Prof. L. D. Conkling,
Montana State College
Bernard E. Gray, Chief Highway Engineer
The Asphalt Institute, New York City.
W. M. Cobleigh, Dean of Engineering,
Montana State College

11:45

Announcements and Luncheon Recess

PROGRAM

1:00

The National Highway Problem
Hon. Burton K. Wheeler,
Senior U. S. Senator from Montana

1:30

Developments and Fundamentals of Successful Bituminous Practice

F. C. Lang, Professor of Highway Engineering, University of Minnesota, and Engineer of Tests, Inspection and Research, Minnesota Highway Department

This paper is an Analysis and Review of papers prepared by:

C. F. Ramey, Assistant Chief Chemist,
Standard Oil Company of California

Levi Muir, Materials Engineer,
E. C. Knowlton, Assistant Engineer,
Utah State Road Commission

H. R. MacKenzie, Chief Engineer,
N. W. McLeod, Research Engineer,
Department of Highways,
Province of Saskatchewan, Canada

J. W. Kushing, Research and Testing Engineer,
J. G. Schaub, Ass't. Construction Engineer,
Michigan Highway Department

A. E. Stoddard, Ass't. Engineer of Materials and Tests,
Iowa State Highway Commission

H. Allen, Materials Engineer, L. L. Marsh,
Ass't. Maintenance Engineer,
J. R. Benson, Assigned to Bituminous Research,
Kansas Highway Commission

2:30

Recess

PROGRAM

2:45

Conference on Developments and Fundamentals of Successful Bituminous Practice
Conference Board:

F. C. Lang, Chairman, Professor of Highway Engineering, University of Minnesota, and Engineer of Tests, Inspection and Research, Minnesota Highway Dept.

R. A. Allen, State Highway Engineer, Nevada Department of Highways

H. R. MacKenzie, Chief Engineer, Department of Highways, Province of Saskatchewan, Canada

C. F. Ramey, Ass't. Chief Chemist, Standard Oil Company of California, San Francisco

J. W. Kushing, Research and Testing Engineer, Michigan Highway Department

A. E. Stoddard, Ass't. Engineer of Materials and Tests, Iowa State Highway Commission

H. Allen, Materials Engineer, Kansas State Highway Commission

J. W. Powers, Materials Engineer, Arizona State Highway Commission

Levi Muir, Materials Engineer, Utah State Road Commission

F. R. Corbett, Chief Chemist, Yale Oil Corporation, Montana

Dr. S. K. Loy, Standard Oil Company of Indiana, Casper, Wyoming

5:00
Recess

5:30-6:30
Wet the Whistle Hour

7:00
Grub Pile
(Chuck Wagon Feed)

9:00-12:00
Entertainment and Dance

PROGRAM

Wednesday, September 9th

General Chairman,
E. B. Donohue, Ass't. State Highway Engineer,
Montana State Highway Commission

9:00

Developments in Practical Design and Construction of Bituminous Surfaces

N. F. McCoy, Highway Engineer,
Bureau of Public Roads, San Francisco

This paper is an Analysis and Review of papers prepared by:

Don Bourne, The Asphalt Institute,
Olympia, Washington

W. A. Norris, Highway Contractor,
Cheyenne, Wyoming

J. N. Roherty, Research Engineer,
North Dakota Highway Commission

A. H. Benedict, Materials Engineer,
Bureau of Public Roads, Portland, Ore.

F. V. Reagel, Engineer of Materials,
Missouri State Highway Department

F. S. Gilmore, Highway Engineer,
The Asphalt Institute, Kansas City, Mo.

Van T. Moon, State Highway Engineer,
Oklahoma State Highway Commission

10:00
Recess

PROGRAM

10:15

Conference on Developments in Practical Design and Construction of Bituminous Surfaces

Conference Board:

N. F. McCoy, Chairman, Highway Engineer,
Bureau of Public Roads, San Francisco

W. W. Zass, Chief Engineer,
Arkansas State Highway Commission

Van T. Moon, State Highway Engineer,
Oklahoma State Highway Commission

J. H. Stemmer, Director of Highways,
Idaho Department of Public Works

Chas. D. Vail, State Highway Engineer,
Colorado State Highway Department

F. S. Gilmore, Highway Engineer,
The Asphalt Institute, Kansas City, Mo.

F. V. Reagel, Engineer of Materials,
Missouri State Highway Department

J. N. Roherty, Research Engineer,
North Dakota Highway Commission

Don Bourne, The Asphalt Institute,
Olympia, Washington

A. T. Bleck, Construction Engineer,
Wisconsin State Highway Commission

W. A. Norris, Highway Contractor,
Cheyenne, Wyoming

12:00
Luncheon Recess

PROGRAM

1:00

National Highway Legislation,
Hon. Roy E. Ayers, Congressman,
2nd District, Montana

1:30

Maintenance of Bituminous Surfaces,
H. G. Nevitt, Manager,
Road Oil and Asphalt Division,
Socony-Vacuum Oil Company, White Eagle Div.
Kansas City, Missouri

This paper is an Analysis and Review of papers prepared by:

R. P. Newland, Division Engineer,
Washington State Highway Department

D. L. Cheney, Bituminous Engineer,
Seward Mason, Testing Engineer,
Montana State Highway Commission

W. N. Lovejoy, Construction Engineer,
J. F. Jacobs, Maintenance Engineer,
South Dakota State Highway Commission

L. L. Allen, Ass't. Maintenance Engineer,
Minnesota Department of Highways

T. R. Perry, Bituminous Engineer,
Iowa State Highway Commission

C. M. Duff, Professor of Engineering,
University of Nebraska, Testing Engineer,
Nebraska Department of Roads and Irrigation

L. C. Campbell, Materials Engineer,
New Mexico State Highway Department

2:30
Recess

PROGRAM

2:45

Conference on Maintenance of Bituminous Surfaces:

Conference Board:

H. G. Nevitt, Chairman, Manager Road Oil and Asphalt Division, Socony-Vacuum Oil Company, White Eagle Division, Kansas City, Missouri

C. A. Davidson, Highway Commissioner, Department of Public Works, Province of Alberta, Canada

W. J. Flannigan, Highway Commissioner, North Dakota Department of State Highways

James B. True, Superintendent-Engineer, Wyoming State Highway Department

C. M. Duff, Professor of Engineering, University of Nebraska, Testing Engineer, Nebraska Department of Roads and Irrigation

T. R. Perry, Bituminous Engineer, Iowa State Highway Commission

L. C. Campbell, Materials Engineer, New Mexico State Highway Department

T. H. Dennis, Maintenance Engineer, California Department of Public Works, Division of Highways

R. P. Newland, Division Engineer, Washington State Highway Department

A. C. Waller, Materials and Oiling Engineer, Idaho Department of Public Works

Carl L. Reid, Testing Engineer, Oklahoma State Highway Commission

Seward Mason, Testing Engineer, Montana State Highway Commission

5:30-6:30

Lying and Bragging Hour

7:00

Banquet—Dining Room, Many Glacier Hotel

9:00-12:00

Entertainment and Dance

PROGRAM

Thursday, September 10th

Presiding,
D. A. McKinnon, State Highway Engineer,
Montana State Highway Commission

9:00

Report of Committee on Coordination of Research in Bituminous Work, and Business Meeting

10:00

Inspection Trip:

Bituminous Construction in Glacier Park via Trans-Mountain Highway over Logan Pass

1:00

Lunch—Lake McDonald Hotel

2:00

Adjournment—Return to Many Glacier Hotel or continuation of alternate inspection trips conducted by Montana Highway Dept.

Trips as Follows:

Butte and Mines

Fort Peck and Dam

West Montana Roads and Lakes

NAEGELE PRINTING CO., HELENA, MONT.

Group picture of delegates attending the Second Annual Montana Bituminous Conference, Many Glacier Hotel, Glacier National Park

D. A. McKINNON

STATE HIGHWAY ENGINEER, MONTANA STATE HIGHWAY COMMISSION

GENERAL CHAIRMAN

SECOND ANNUAL MONTANA BITUMINOUS CONFERENCE

E. B. DONOHUE

ASSISTANT STATE HIGHWAY ENGINEER, MONTANA STATE HIGHWAY COMMISSION

ASSISTANT GENERAL CHAIRMAN

MONTANA BITUMINOUS CONFERENCE

HONORABLE ROY E. AYERS

D. A. McKinnon
Montana State Highway Engineer
2nd Annual Montana Bituminous Conference
Many Glacier Hotel
Glacier National Park

I sincerely regret that circumstances beyond my control will not permit my attendance in person at the 2nd Annual Montana Bituminous Conference.

It so happens that at this time our government officials who are in direct charge of the drouth and relief administration in Washington are making a personal visit to our state for the purpose of studying and familiarizing themselves with conditions existent here, and allocations of Federal Funds to assist us in coping with these emergencies during the coming year will perhaps be greatly dependent on their visit and their findings. It is therefore extremely important that I be on hand to assist them in every way possible.

Please express to the Conference delegates my welcome to the State of Montana and my hope that your meeting will be highly successful.

HON. ROY E. AYERS
Congressman, 2nd Congressional District, State of Montana.

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MONTANA STATE HIGHWAY COMMISSION

NAEGELE PRINTING CO., HELENA, MONT.

FOREWORD

During the past few years there has developed a national interest in, and demand for, low cost bituminous surfaces. This has been brought about by rapidly increasing traffic, increased speed and the natural trend toward higher type surfaces which have necessitated and demanded a road surface free of dust with a smooth, comfortable riding surface. Further, increased maintenance costs on gravel roads, brought about by the appalling loss in thickness resulting from wear under traffic, has made necessary some type of surface whereby this rapid and costly deterioration can be prevented and the surface maintained in its original condition insofar as possible.

However, funds for highway construction have not kept pace with the increasing demand and need for improved surfaces, particularly so in the Western States with their large areas and comparatively small populations.

In Montana, which is the third largest state in the Union, we have a population of less than 550,000 while the area of the state is approximately 147,000 square miles. It has therefore been necessary that the greater part of our moneys available for highway construction be spent in initial stages of the construction; that is, the grading and gravelling of the large mileage of roads on the highway system. It has not been, nor does it appear that it will be, possible to utilize any great part of these funds in the construction of high type surfaces.

Consequently, any improved type of surface must be low in cost and, as the major cost in this type of construction is the required materials, it was very evident that the materials used must be those which were easily available. Uniform aggregate meeting highly eliminative specifications could not be produced and shipped about the state to points where they might be required without prohibitive production and transportation costs.

There was then only one alternative: Roadside production of materials, utilizing those materials available in the locality in which they were to be used. This meant that many different kinds and types of aggregate would have to be used and that it would be necessary to design the surface and select asphaltic binders suitable for use with each of the different types of mineral aggregate.

This presented a very consequential and complicated problem rendering necessary detailed studies of the mineral aggregates and asphaltic materials to be used, careful consideration of the methods of manipulation necessary for their combination, and further and more thorough study and improvement of specifications governing the materials and their usage on the roadway.

As the construction and maintenance of low cost bituminous surfaces was a comparatively new phase of highway engineering, and although we had attained fair success, we believed that more enduring, satisfactory and perhaps lower cost surfaces could be constructed through an increased knowledge of the fundamental characteristics of asphaltic materials and mineral aggregates, study of construction methods and design, and a more thorough analysis of failures.

Believing that a very important step in this direction would be the calling together of all engineers in the employ of the Montana Highway Department for a group study and conference on the construction and maintenance of these surfaces, we outlined the program of the First Montana Bituminous Conference. To obtain all the knowledge possible, it was planned to invite several of the more important leaders in the bituminous field throughout the Western States to attend this meeting, which would primarily be for the benefit of the engineers employed by the Montana State Highway Commission.

Shortly after outlining the tentative program for this meeting, the fact was brought out that a Conference of this kind, devoted entirely to one phase of highway construction, had never been held, and believing that many of the States and some Provinces of Canada might be interested in attending and taking part in such a meeting, the tentative program was revised and a program was prepared which would cover all phases of bituminous construction and maintenance, where engineers, chemists, technologists, and others interested in bituminous work could get together for a group study of specifications, construction methods and designs, and for a thorough exchange of practices, experiences, attainments, and ideas.

This Conference was held in Butte, Montana, on November 12th, 13th, and 14th, 1935. It was attended by 140 persons representing 14 states. The meeting was so successful that at its conclusion it was requested that the Montana Bituminous Conference be made an annual event.

Therefore, the program for the Second Annual Montana Bituminous Conference was outlined with the idea of covering, insofar as possible, every phase of bituminous practice with reference to maintenance, as well as construction and design, and to cover the practices and experience of each state or district with respect to these different phases.

Accordingly, the Conference program was divided into four sections, each section covering an entirely different field in bituminous work. Realizing the increasing need for more thorough scientific engineering and the inauguration of a detailed and far-reaching program of bituminous research, the first section was devoted to a review of analytical engineering methods and research as applied to bituminous construction. The paper presented on this section covered the more important phases of analytical engineering and research work and in conclusion the author brought out very strongly the need for the carrying out of an extensive program of bituminous research and outlined a project which might be carried on by the Conference.

The paper was followed by a very interesting and enlightening discussion of the subject which resulted in the appointment of a special committee to study the research problem and report back to the Conference with any recommendations. This committee introduced a resolution for the adoption of the procedure outlined in the author's paper on The Review of Analytical Engineering Methods and Research. This resolution was unanimously adopted by the Conference.

The following sections of the Conference were based on (1) Developments and Fundamentals of Successful Bituminous Practice, (2) Developments in Practical Design and Construction of Bituminous Surfaces, and (3) Maintenance of Bituminous surfaces.

In planning the preparation of the paper on each section, the territory, which it was known at that time would be interested in and report at the Conference, was divided into seven groups or districts. These districts were comprised of nineteen states and one Canadian Province. A chairman was designated for each section of the Conference and one person from each state was assigned the preparation of a paper on one of the three sections. Assignments for the preparation of these papers were made in March, 1936. Papers were prepared during the spring and summer months and on a set date previous to the opening of the Conference, one copy of each paper was forwarded to the section chairman for his review and comment, and ten days previous to the opening of the Conference each author forwarded the Montana State Highway Commission three hundred mimeographed copies of his paper. These copies were handed out to delegates at the time of their registration so that they might read them prior to or during the Conference and be better prepared for the discussion periods. None of these papers were presented at the Conference. The chairman of each section presented a summary and review of all the papers in a group, this summary of course bringing out the highlights, the general trend of each particular sub-division of bituminous practice, and the prevailing practice in each particular district.

The previously prepared papers, together with the summaries by the section chairmen, represent the greatest mass of information on all phases of bituminous practice ever assembled.

Following the presentation of each summary by the chairman, discussion periods were held. The persons who prepared papers, together with other leaders in the bituminous field, served on conference boards to lead in and assist with the discussion. The discussions were ably conducted by the chairman of each section and it was felt by many that the greatest benefit derived from the Conference was through these periods of dissertation where experiences and observations were exchanged and where general and individual problems as well as many of the important points brought out in the papers were reviewed and thoroughly discoursed.

Montana State Highway Engineer.

OPENING SESSION

Many Glacier Hotel

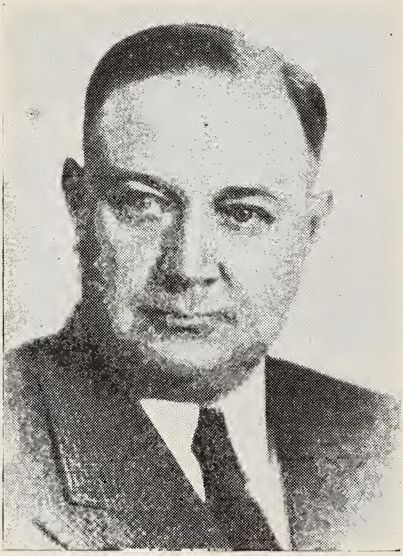
9:00 A. M., September 8th, 1936

D. A. McKINNON, Montana State Highway Engineer
General Chairman

THE SECOND ANNUAL BITUMINOUS CONFERENCE WAS OPENED AND CALLED TO ORDER BY D. A. McKINNON, GENERAL CHAIRMAN, WHO PRESENTED DR. HARRY J. McGREGOR, CHAIRMAN OF THE MONTANA HIGHWAY COMMISSION.

ADDRESS OF WELCOME

By Dr. Harry J. McGregor, Chairman, Montana Highway Commission..



It is with a great deal of pleasure that the Montana State Highway Commission welcomes to this State the Second Annual Montana Bituminous Conference and the attendants thereof.

We hope that on this occasion you will combine the theoretical study of bituminous road construction and its contents with enjoyment of the scenic beauties of this Many Glaciers Hotel setting and also the other scenic beauties of Glacier National Park. We are anxious that you cover as many of the recreational spots of the Park as possible during your stay in Montana.

It has been through the efforts of the engineering profession, and particularly those who have selected road construction as a special line, which, of course, includes bituminous treatment of highways, that Montana during the past few years has become one of the greatest tourist states in the Union during the summer months. With the completion of our bituminous highways, we are now offering the scenic values of our State, too numerous to mention, and in which we include our two National Parks. By changing the location of the Conference each year, we hope to give the members of this Conference the opportunity of seeing the entire State during the years to come. The union of study and recreation in a meeting of this kind is bound to prove successful and tends toward more progressive theoretical study of the subject involved.

During the past few years I have given the matter of road construction, in all its phases, serious study, which has resulted in the formation of an opinion regarding the engineering profession, perhaps overlooked heretofore. It appears to me that in the engineering profession today success must be accompanied by a humanitarian spirit. It is only natural that I, a member of the medical profession, should look at the work of another profession in this light. Nevertheless, with the great loss of life upon the American highways today, last year reaching some 36,000; and with the great number of afflictions received upon the highways during the past year, totaling 1,250,000 people injured or maimed in some manner, the highway engineer, from the time a survey is started for the construction of a piece of road until its final completion, must bear in mind at all times the elimination of all death hazards in his work. This, I know, you are doing. In the medical profession we do our utmost to eliminate diseases and are constantly doing research work, under national, state and endowment funds, for this purpose. During the past twenty-five years of my experience, the accomplishment in the field of disease prevention has been one of the outstanding advancements of any science during that quarter of a century. We term this work "Preventive Medicine," and its sole function is to prevent loss of lives from disease. Now, it seems to me, that the rapidly increasing miles of highways, the changing traffic problems, and the advancement in construction of all motor vehicles, has made a place for a specialized branch of engineering, to which we may apply the term "Preventive Accident Engineering."

This branch of engineering seems very difficult today. Its advancement will be measured by the number of lives saved and the number of injuries prevented upon the highways of this country. If it were a singular problem, involving only your own profession, one might hope for quick results, but such is not the case. In order to bring about results it will be necessary for you to anticipate what is in the minds of the automobile engineers so as to enable you to formulate your engineering constructions accordingly. Furthermore, when we speak of the automobile engineers, we must take into consideration all those responsible for its entire makeup, even including those applying themselves to the manufacture of automobile tires.

As I see the problem, the highway engineer must sponsor an educational program in the use of the highways. This instruction should apply to the driving of cars, to the driving of trucks and motorcycles and also to the proper methods of walking upon the highways by pedestrians. This education must have its beginning with the primary reader and must be extended on throughout the educational life of an individual up to the time he is ready to use the highways. This country has educated its people against loss of life in almost every regard, excepting that of accidents upon the highways. And, while it is unfair to place the burden of blame for loss of life upon the highway engineer, because today he is confronted by a problem, which came into existence so rapidly that it had reached large proportions before it was actually realized; it is right, however, to encourage your profession to make every effort to remedy the situation. There should be a central control for all highway work of the various states, which control must include the necessary power to act for law enforcement, and this control should be placed in the hands of the highway engineers. When this is accomplished, those engaged in highway construction, of whatever branch, will respond to the responsibility put upon them in the same manner as the medical profession has responded in the field of Preventive Medicine, and results will necessarily follow. I sincerely hope that more stress will be placed upon this subject by your profession.

I believe it should be your first act to set up in each State a Preventive Accident Engineering Board; which Board would perhaps work in conjunction with a National Board to handle this subject for the American people. Heretofore this work has been carried on by enforcement officers, chiefly without the desired results. With the scientific application of the engineering profession to this problem and the carrying out of these ideas in reference to safety by the enforcement organization, after a thorough educational course by all our citizens, we may expect to get somewhere. If the present death rate and accident rate continues, I predict that the educational work will be carried not only through the lower educational institutions, but will also form the basis for master degrees in that special line of engineering; and that the engineering profession of the United States will take a place in the hearts of the people of this country in the field of Accident Prevention Engineering, as my own profession has taken in the field of Preventive Medicine.

ADDRESS OF WELCOME TO GLACIER NATIONAL PARK

By E. T. Scoyen, Superintendent.

I would like to apologize to you for not being on time this morning. I won't go into detail in giving the reasons why I was not because that might be as embarrassing to one of the other speakers this afternoon as it is to me, so I will just say that we have been quite busy in the park as a result of a couple of youngsters, one sixteen and the other ten, who decided to go mountain climbing, and we spent all last night and part of the morning looking for them, finally finding them this morning. This is one of the things that happen to us sometimes which upset our schedules.

In bidding you welcome to Montana's park, Glacier National Park, I do so in the name of the United States Department of the Interior and the National Park Service which have the administration of these areas under supervision. Glacier happens to be the fifth national park in which I have served. As a matter of fact, I was raised at Mammoth Hot Springs in Yellowstone Park and lived there twenty-seven years. Except for the pay I drew from Uncle Sam as a gob in the Navy during the war, every cent I have earned has been in national parks. I am just saying this to you because, as I said, I have worked in five national parks. Since I have been in the National Parks Service I have visited a good many states and I know some of you here from other states are very proud of your own national parks in those states, and you have good reason for feeling that way. It is rather hard to compare national parks and you cannot say one is better or one not quite so good as another. I do feel, after having worked in the national parks in this western country, that Glacier must be considered the most sublime wilderness area in the United States. Within an area of 1534 square miles, 942,000 acres, we only have 80 miles of improved highways. Secondary roads included, there are only 140 miles of roads in this great area. It is largely a trail park, a park consisting of about 1100 miles of trails going back into these great mountains. We have about 250 lakes and we hope you will get a chance to see some of them before you get out of the park. We have waterfalls, so many that some which would be famous any place else in the world do not even have names. We have wonderful streams, wonderful glaciers and I think you can find something to suit almost any vacation need in Glacier Park. It doesn't make any difference just what kind of a vacation you want, you can find it here. We hope to keep the park a wilderness area and for that reason we feel that road construction in the park itself has been largely completed.

The Going-to-the-Sun Highway which goes over Logan Pass, which some of you have not been over, and which I hope you will go over before leaving the park, is, of course, our main road. This takes you by way of our largest lakes, up two of our largest mountain valleys, by one of the largest glaciers, past the highest waterfalls, right under some of the largest mountains and through some of our finest forests.

I suppose most of you have been noticing the recent disaster which we had, which is regrettable. However, those things come about through a combination of various circumstances. Perhaps the continued drought for the last three or four years brought it about more than any other single thing. I do not know just what we can do with our forests if we do not get rain.

We are trying to see what is happening to our glaciers here in the park. During the last four years, prior to this year, they have receded a total of 260 feet, which shouldn't worry you much as they are several miles long. This year they have receded 465 feet.

I don't think that all the fires we have had in the park and all that we will ever have in the future will do any great damage to it, as Nature has a way of healing scars rapidly.

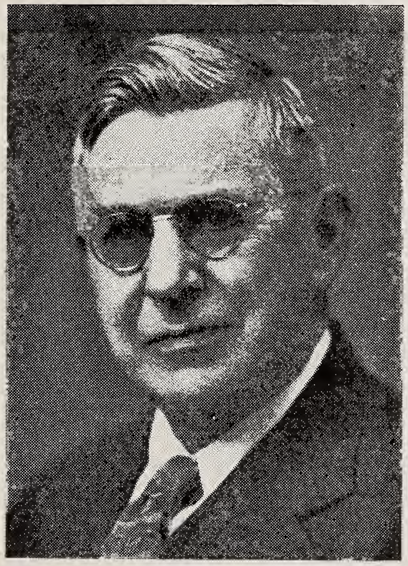
I hope you will find time to go around and enjoy the park while you are here in Glacier and you will find that there are lots of sections which have not been burned at all. We are sorry that the fishing has not been as good this year as in previous years as the fish seem to have gone to the bottom of the lakes and do not come up. With the cooler weather you might catch some.

I wish to again bid you welcome to Glacier National Park and I hope that you all have a good time while you are here.

SECTION I.

REVIEW OF ANALYTICAL ENGINEERING METHODS AND RESEARCH AS APPLIED TO BITUMINOUS CONSTRUCTION

By Professor L. D. Conkling,
Montana State College Civil Engineering Department.



Mr. Chairman and Gentlemen:

In the response to the roll call of the states, I heard the gentlemen from Alabama respond and they thought they had travelled a long ways to get here, but I really believe that I have travelled a greater distance to get to this Conference than any one present.

On the fifth of August, Mr. Donohue informed me that I was to be the first speaker on this program. The next morning, August 6th, Mrs. Conkling and myself started for Glacier Park by way of Portland, Maine. We arrived yesterday and we travelled something over 6500 miles, visiting fifteen different states. We had an object in view and that was to find out for ourselves by observation what the other states are doing in bituminous construction. We travelled the main highways, the state highways, the county highways and the by-ways—the common dirt road of my boyhood days in the east—and we travelled over wonderful concrete roads—U. S. Highway No. 30. You, gentlemen, all know what that road is through Nebraska and from there on east. When we got back into the real eastern section of the country, we were very much pleased to see that the East is waking up to the importance of bituminous construction. They are going back into their recreational areas and opening them, as Montana has shown them how, and you may travel through the states of Maine, Wisconsin, New Hampshire and Minnesota on good bituminous construction.

Another thing that impressed me, and which is along the lines of Dr. McGregor's remarks, was the control of traffic. I am interested in all phases of engineering because of my position as head of the Civil Engineering Department of Montana State, and we have tried to touch upon them all.

In the phase of traffic control, we observed the law enforcement agencies of the several states through which we passed, and the State of Montana ranks just as high as any others in their traffic control. In the eastern states the one thing that impressed me as almost startling was the utter disregard of traffic signs, the people in New York state cannot read English. They do not know what "Stop" signs mean and being from the great wide-open spaces of Montana, my heart was in my mouth most of the time.

This brought to my mind a little sign that I saw in South Dakota a good many years ago. A great, big sign greeted us and it read something like this:

"Bad grades, many curves. Keep to the right, you might meet a fool."

Back there in the east they are so pressed for time they must save the minutes. They cut on the inside of curves and never regard the line that is supposed to keep them in order. Something to make you think.

The paper I am going to present deals with some of the different phases of Analytical Engineering Methods and Research as applied to Bituminous Construction.

The first phase I am going to attempt to cover in reviewing the technical literature dealing with the low cost bituminous roads, seems to be grouped into different divisions as follows:

1. What is our problem?

I am going to quote from an article entitled "Scientific Road Construction" published in 1913 by the Standard Oil Company of California. The following is an abstract and review of the article published at that time.

"The movement for good roads is attracting world-wide attention. The object of this bulletin is to call attention to the fundamental principles of road building, and the necessity for the thorough examination of the materials used in road construction.

The character of modern traffic has altered considerably in the last ten years. Roads are now subjected to greater maximum loads by the use of traction engines and heavier trucks. Loads are carried more rapidly by auto-trucks and heavy touring cars. From these conditions, new road problems have arisen.

A road, street or highway is a structure built to withstand the stresses imposed by traffic and climatic forces. The main stresses are due to:

1. Forces caused by dead and live loads.
2. Forces caused by impact.
3. Forces caused by shearing.
4. Forces caused by suction.
5. Forces caused by climate."

* * * *

The bulletin discusses the nature of these forces and draws the following conclusions:

"1st—For Dead and Live Loads: A base is required that has strength and rigidity.

2nd—For Impact: A material is required to absorb shocks and prevent disintegration.

3rd—For Shearing: A material is required to prevent disintegration.

4th—For Suction: A material is required that will form a bond and prevent the particles being carried away.

5th—To overcome climatic forces we must have: (a) A material with a greater expansion and contraction than rock and one which will prevent the road from disintegrating; (b) A material which will make the road impervious to water."

Quoting further from this bulletin:

REASONS FOR FAILURE

"Modern engineering work is conducted in accordance with scientific standards. * * * If not approached in this manner the road may fail for the following reasons:

Sub-base non-draining.
Sub-base of a material requiring special treatment.
Sub-base too springy because of organic matter.
Base not having properly graded material.

Base having material that does not macadamize.
Base having material that is not homogeneous.
Base being too porous.
Material in surface being non-cementing with asphaltum.
Material in surface being improperly graded.
Material in surface being too soft.
Material in surface having too great or too small a percentage of fines.
Material in surface being too round.
Surface layer too thick.
Surface layer with too much asphaltum.
Surface layer with insufficient asphaltum.
Various materials insufficiently mixed.
Various materials insufficiently rolled.
Various layers improperly rolled.
Asphaltum of the wrong grade being used.
Water in the asphaltum."

The above was published in 1913. It seems to me that these statements are as true today as they were twenty-three years ago. It is my hope in this paper to briefly summarize the advance that has been made in the design of the flexible type of low cost pavements.

The next group seems to be those discussing the fundamentals of paving and road design. I believe we are justified in assuming a pavement to be a structure and approach the problem in the same manner as we would any other type of structure. Before we can do this, we must know our bituminous and aggregate material. As an example of the method of approach, I wish to quote the following article:

SOIL SCIENCE RELATING TO FLEXIBLE TYPE ROAD SURFACES

By C. A. Hogentogler
Senior Highway Engineer, U. S. Bureau of Public Roads

Synopsis

The theory of stability of soils and the methods used to produce stabilization of subgrade soils are presented. The essential features of stabilization include prevention of clay and silt soils from becoming detrimentally wet, incorporation of granular materials in clay soils and furnishing granular soils with cohesive binder. General methods are enumerated as follows:

1. Selection of natural soils with granular material and binder which furnishes high stability.
2. Adding soil binder to granular materials, or adding granular material to clays.
3. Treating graded soils with deliquescent materials.
4. Waterproofing soils with surface treatments of bituminous materials.
5. Densification of natural soils by special manipulation in combination with admixtures of physical or chemical materials other than soil to eliminate permanently those clay and colloidal properties productive of volume change.

Since comprehension of the practicability of permanently densifying soils is facilitated by understanding the performance of materials when in films of molecular thickness, the discussion deals especially with the theory of matter in the film phase, the wetting of solids by liquids, absorption as affected by electrolytic properties and the densification of soil at optimum moisture content.

Until we have sufficient knowledge of the properties of the component parts of our pavement to definitely assign values to constants in equations and to evaluate the variables, we must depend upon Empirical formulas for design. This is well illustrated by the McKesson-Frickstad formula for the per cent of oil in the mat.

The authors make the following statement:

"An Empirical formula has been developed which is tentatively submitted with the thought that it may be of value in estimating the amount of oil required. It is not applicable to porous or absorbent materials, such as cinders or lava, but otherwise it appears to give results which are consistent with service obtained from various mixes."

"PUBLIC ROADS." September 1927
"LIGHT ASPHALTIC OIL ROAD SURFACES"

By C. L. McKesson, Materials and Research Engineer,
California Dept. of Public Works
W. N. Frickstad, Highway Engineer,
U. S. Bureau of Public Roads.

The authors present very clearly and in considerable detail the practice and experience of California and Oregon with different surfaces for light traffic roads.

They state their principal conclusions as follows:

1. Light asphaltic residual treatment as practiced in California and Oregon have demonstrated their utility in the preservation of existing metaled road surfaces and are justified in places where the cost of the oil is not prohibitive.
2. Oil treatment has substantially reduced maintenance and replacement charges on fine crushed rock and gravel roads in Oregon and California. The first cost is frequently less than the value of the metal lost yearly from the same road before treatment. * * *
3. Oil treatment improves service and is, therefore, popular with the public. It eliminates dust, increases smoothness, decreases tire wear, and lowers fuel consumption.
4. Any road in Oregon or California which has justified improvement with a fine rock or gravel surface warrants the additional expense of a light oil treatment. * * *
5. An efficient maintenance organization is essential to the success of light oil treatments. Maintenance must be immediate and continuous, otherwise oiling will be unsuccessful and should not be undertaken.
6. The recorded success with light oils should not stop continued development of present practices or experimentation with heavy asphalts.
7. In the matter of new construction no conclusions can yet be formulated as to the relative merits of building fine crushed rock or gravel surfaces, to be immediately oil-treated, or adopting some form of bituminous macadam.
8. Protection of vehicles from freshly applied oils is indispensable; otherwise, damage to traffic may more than offset the benefits resulting from treatments.

9. Examples of oil-treated natural soil roads furnish impressive figures of good service and low costs. This type has a larger field than has heretofore been realized where soil, climate and traffic are favorable. It deserves more scientific study and active consideration.

10. Precautions:

The immediate improvement that generally follows oil treatment has sometimes encouraged a feeling that almost any road may be successfully treated by almost any method. Subsequent complete or partial failure has discredited the process. The facts are that success will be proportionate to the suitability of physical conditions, intelligence of supervision, and skillfulness of workmanship. The following are important precautions to be observed:

(a) Unless there is a maintenance organization accustomed to giving daily attention to necessary repairs, oiling should not be undertaken. Delay and neglect cause rapid destruction and discredit the process with the public, which expects more of an oiled than of an untreated road. * * *

(b) There must be sufficient thickness of metal to carry the expected traffic.

(c) The width of the stone surfacing should be adequate. Vehicles turning on and off the oiled surfaces tend to crumble the edges.

(d) The metal must be compacted completely from top to bottom if the method of surface treatment is to be used, and at least through the untreated base if the surface-mixing method is to be followed. A layer of loose material between base and mixed top may cause rutting, shoving, or breaking.

(e) For surface treatment, repairs should be completed and the road compacted well in advance of oiling. * * *

(f) All loose material and scales of fines must be removed before the oil is applied to the surface. Sweeping must expose clean rock or gravel firmly embedded.

(g) The texture of the stone surface should be uniform. Results of surface treatment will be poor if portions of the road are porous while other portions are impervious.

(h) Asphaltic materials must be applied uniformly under pressure. Streaks and omissions will be a constant source of future trouble.

(i) Cover material for surface treatment should be coarse rather than fine. Clean chips are the best cover material. Fine material tends to form an unstable mat and absorbs oil which should be allowed to penetrate. Success with surface-mixing method requires sufficient insert fines to fill all voids. If not already present they must be added. * * *

(j) Heavy clay binder mingled with the road metal greatly reduces the probability of success with oil treatment. A road that breaks up in the spring or that becomes muddy in wet weather should not be oiled."

The authors make the following statements in regard to "Tests of Surface Mixtures":

"Analysis of samples taken from surface-mixed roadways show that apparently the amount of 'fuel-oil' required in a surface mixture is about three-fourths the quantity of asphalt that would be used for the same grading. So long as the correct amount of oil is used, it appears that wide variations in grading may be tolerated. Samples were taken from successful bituminous surfaces produced by mixing method where the material varied from silt to crushed gravel.

An empirical formula has been developed which is tentatively submitted with the thought that it may be of value in estimating the amount of oil required. It is not applicable to porous or absorbent materials such as cinders or lava, but otherwise it appears to give results which are consistent with service obtained from various mixes. The formula is:

$$P=0.015a+0.03b+0.17c$$

in which P is the percentage of oil required, a is the percentage of metal retained on a 10-mesh sieve, b in the percent of metal passing a 10-mesh sieve and retained on the 200-mesh sieve, c is the percentage passing the 200-mess sieve.

The stain test apparently furnishes the only reliable means for determining the amount of oil required for absorbent materials.

Used with non-absorbent materials, the proportion of oil calculated from the formula has furnished satisfactory stains from many mixtures prepared in the laboratory; but even with such materials the indications of the stain test seem to be a more reliable guide than the formula in case of conflict between the two methods."

Under the topic of "Selection of the Method and Oil for Treatment" the authors make the following statements:

"From the foregoing description and analysis of the methods of surface treatment and surface mixing—the two methods of treating crushed rock and gravel roads thus far developed—it is apparent that the selection of one or the other for treatment of a particular road is a matter requiring the exercise of seasoned judgment.

Method of Surface Treatment

The method of surface treatment is adapted to compacted material only. Usually a road is in best condition for treatment after being subjected to traffic for a time. However, new surfacing material, if thoroughly compacted with water and traffic during construction, is very satisfactory. Being somewhat porous, such material absorbs oil readily.

An old road containing considerable coarse material, if it can be repaired well in advance, is well adapted to surface treatment because the large stones are well anchored.

Method of Surface Mixing

This treatment is adapted to any crushed rock or gravel road which is in need of the addition of considerable new material to restore its thickness, or which, because of lack of binder or climatic condition, is not tightly bound.

The surface-mixing method is the only one that is adapted to the treatment of a loose surface; but in the use of this method, as in surface treatment, the base course should be thoroughly compacted. The presence of material larger than one inch presents mechanical difficulties.

Either Type

A well compacted, fine crushed rock or gravel surface of adequate thickness may be treated successfully by either method. Choice depends upon relative service and life, about which there is no definite information. * * *

Oil for Surface Treatments and Surface Mixing

In the treatment of crushed rock and gravel roads described in this report the bituminous binder has usually consisted of the material known locally on the Pacific Coast as "fuel oil," or the lightest grades of "road oil." Both are asphaltic base products.

The material sold as "fuel oil" has an asphaltic content up to about 70 per cent and a viscosity, Saybolt-Furol, up to 300 at 122 degrees F. The term "road oil" has been applied to oil residuum having an asphaltic content of 70 to 80 per cent, being thus distinguished from the heavier residuums which are usually termed "asphalts" of E or D grades.

Asphalt content in this connection and as used in this report is the perecentage of residue having a penetration of 80 to 77 degrees F. as "fuel oils" have usually been specified by specific gravity in degrees Baume, or by viscosity rather than by asphaltic content.

Viscosity may vary widely independently of asphaltic content, which permits selection of various grades for special uses while specifying a single range of asphalt content, as 60 to 70 per cent. Maximum penetration can be secured by using oil of low viscosity. For mixed treatments medium viscosity appears desirable, because the oils with high viscosity are harder to handle and more difficult to mix with road metal. In surface treatment work where chips are to be used in quantity, high viscosity is desirable.

All of the grades of "fuel oil" used in bituminous treatment are more uniformly distributed if heated to 150 to 200 degrees F.

In the April 24th, 1930, issue of the Engineering News Record appeared an article by Mr. H. G. Nevitt entitled "Rational Design of Asphaltic Oil Roads." In this article Mr. Nevitt presents what he calls an improved formula. In the formula and in the paper Mr. Nevitt attempts to evaluate the characteristics of the aggregate. He discusses the McKesson-Frickstad formula modified for Utah, Wyoming and the other states and finally says he will develop an improved formula.

Then the author discusses in detail the various constants or variables and presents tables and diagrams to demonstrate the different values. He sums up his article with an example of computations. He takes for example an aggregate with 45.5 per cent passing the 10-mesh sieve and 8 per cent passing the 200-mesh sieve.

He carries on his discussion and finally gets the various formulae for the constants and derives from the formula 5.2 per cent oil to be added to the aggregate.

The charts and tables giving the values of the various coefficients are based upon the average experience with the materials available, and some are, of course, subject to correction and refinement. It is Mr. Nevitt's desire to invite discussion as to possible refinement and as to additional values for other materials. It is thought, however, that the formula advanced is correct in its basic terms and should offer a foundation for the development of more exact theory of design. The following is quoted from Mr. Nevitt's article:

RATIONAL DESIGN OF ASPHALTIC-OIL ROADS

By H. G. Nevitt, Manager, Road Oil and Asphalt Dept.
White Eagle Oil Corporation, Casper, Wyo.

Published in the Engineering News-Record, April 24, 1930.

Mr. Nevitt's article is a "Review and Appraisal of Previous Formulae." He also suggests a new formula for determining the oil content for various materials in Surface-mixed Asphaltic-oil roads.

The article states the several formulae as follows:

McKesson-Frickstad

$$P=0.015a+0.03b+0.17c$$

The Utah formula which adds a factor "H" depending on the absorption of the aggregate.

$$P=0.02a+0.33b+0.195c+H$$

The Wyoming Highway Department adapted the McKesson-Frickstad or California formula to Wyoming conditions by increasing the oil content 40 per cent.

$$P=(0.015a+0.03b+0.17c)\ 1.4$$

In the above quoted formulae, the following notation is used:

P is the percent by weight of oil to be added to the aggregate.
a is the percent of aggregate retained on the 10-mesh sieve.
b is the percent of aggregate passing 10-mesh and retained on 200-mesh.
c is the percent of aggregate passing the 200-mesh.

The New Mexico Highway Department expresses the formula as follows:

$$P=0.02a+0.07b+0.15c+0.20d$$

P is the percent by weight of oil to be added to the aggregate.
a is the percent of aggregate retained on the 48-mesh Tyler sieve.
b is the percent passing 48-mesh and retained on 100-mesh.
c is the percent passing 100-mesh and retained on 200-mesh.
d is the percent passing the 200-mesh sieve.

The author, Mr. Nevitt, presents the following formula

$$P=MWSFD+V$$

as an "Improved Formula" for determination of the oil content.

The following is quoted from the Engineering-News-Record:

Improved Formula Developed

Obviously, the composition of the mix, on a weight percentage basis, will be affected by characteristics of the mineral aggregate such as the specific gravity of the aggregate in relation to the specific gravity of the oil, shape, texture, relative surface area, size distribution as shown by screen analysis, absorptive properties, and percentage of voids. The viscosity of the oil at test temperatures and under actual climatic conditions in the oiled mat will further influence results.

A method has been formulated which is believed to embody the elements affecting the composition of the mix and to combine these factors in a logical and correct manner. The terms of this formula are tentative as regards the values given the different factors, and are subject to revision, but these represent careful study of oiled roads and mat materials over a considerable period of time and under varied conditions. This method has been developed first to offer a better type of formula, and second to outline certain tentative values for the different coefficients, which may be used as a basis for further study. The formula is expressed as:

$$P = MWSFD + V$$

in which P is the percent by weight of oil to be added to the aggregate, M is an absorption coefficient depending on the materials used in the aggregate, W is a coefficient depending on the relative specific gravity of the dry aggregate and the oil, S is a coefficient depending on the shape and surface texture of the average aggregate particles (predominant consideration being given to those in the 10-mesh range or below), F is a film thickness coefficient depending on the viscosity of the oil and the average climatic conditions encountered, D represents the size distribution of the aggregate as determined by screen analysis, and V is a correction based on the percentage of voids in the dry aggregate.

M, the material or absorption coefficient, is determined by the property of the mineral aggregate of absorbing a certain quantity of oil, with a consequent reduction of the bonding power of this oil. On the basis of present data, Table 2 shows the estimated values for this coefficient. The value of the coefficient for limestone will vary according to the hardness and type of this material, and all values shown will vary more or less according to the properties of material from different localities. Coefficients are given for average conditions, and for more accurate results values for M must be selected as determined by the characteristics of the aggregate materials available in each locality, either by judging from the appearance of the aggregate or by means of some test for absorption, as for example the previously mentioned absorption test of the Utah highway department.

In Table 2, where the material is referred to as coated, the reference is to a deposit on the surface of the aggregate particles of a cementitious coating, of different composition from the aggregate itself. Thus, a hard, non-absorptive sand grain may have a coating of argillaceous, gelatinous or ferruginous nature which may be highly absorptive. In general, material which has undergone considerable erosion, such as river sand, is less likely to show such a coating.

W, the weight coefficient, is proportional to the relation between the specific gravity of the aggregate material and the specific gravity of the oil, and may be taken as unity where the gravity of the aggregate material is 2.65 and the gravity of the oil is 0.97. Other values for W may be read from Table 3. To convert the weight of the oil to terms of volume, as determined by the relative specific gravity of the aggregate and the oil, divide the specific gravity of the aggregate by the specific gravity of the oil. For the percent by volume of the oil to be added to the aggregate, multiply the result by the percent by weight of the oil.

S, the shape coefficient, depends upon the shape and surface texture of the aggregate particles. The more irregular the shape and the rougher the surface the greater will be the surface area of these particles and the higher the perecentage of oil necessary to completely coat the particles. Preliminary suggested values for this coefficient are as follows:

Practically spherical particles with very smooth surfaces	0.75
Almost cubical shape with smooth surfaces	0.85
Fairly cubical shape with smooth surfaces	0.90
Fairly cubical shape with rougher surfaces	0.95
Irregular fracture, angular shape and fairly smooth surfaces	1.00
Irregular fracture, angular shape and irregular surfaces	1.25
Irregular fracture, angular shape and very rough surfaces	1.50

F, the film thickness coefficient, reflects the difference in thickness of oil film required due to variation in the viscosity of the oils in the completed oil mat. This is dependent on two factors: the viscosity of the oil at the standard test temperature, and the actual average climatic conditions encountered by the oil on the road throughout the year. This coefficient may be read from Fig. 1.

D, the aggregate size coefficient, expresses the variation in the size of the aggregate particles, as shown by screen analysis. The smaller aggregate particles have a larger total amount of surface area to be covered by the oil film, but the thickness of the film decreases, almost but not quite offsetting the increase in film area. The resultant effect of these two factors is expressed in the following formula and can be read from Fig. 2:

$$D=(10P_{200}+6P_{10}+80)\div 100$$

in which P_{200} is the **total** amount by weight of the dry aggregate passing the 200-mesh sieve and P_{10} is the **total** amount by weight of the aggregate passing the 10-mesh sieve.

While a factor V, for void correction, appears in the formula, this correction is seldom necessary, except where there is an exceptionally high void content in the aggregate. The percentage of voids in the dry aggregate is computed by some standard method. The weight of the oil to be added to the aggregate is then computed from the first part of the formula, and this weight is converted to percentage by volume by the method given under the discussion of the coefficient W. This oil volume is then subtracted from the percentage of voids in the dry aggregate. If the remaining voids exceed 12 per cent, a volume of oil is added sufficient to fill the voids in excess of 12 per cent. By then reducing this volume to terms of weight, the percentage of additional oil to be added to that already determined by the formula is found. The preceding is of course a rough rule, and judgment may be required in its application to unusual cases showing very high voids.

Example of Computation.

As an example of the application of the formula, take an aggregate with 45.5 per cent passing the 10-mesh sieve and 8 per cent passing the 200-mesh sieve. As 60 per cent of this material passes the ¼-inch screen, the Idaho curve calls for an addition of 4.4 per cent of oil. Working out the value of D as equal to $10P_{200}$ $6P_{10}$ 80 100, the result is 4.33, which would represent the percentage of oil to be added to the aggregate if the other coefficients were taken as unity. However, an examination of the materials will give value for the other coefficients as follows: The aggregate is a moderately coated sand, with a value for M of 1.15; the specific gravity of the oil is 0.97 and the specific gravity of the aggregate 2.65, giving a value of 1 for W; the shape of the particles is "irregular fracture, angular shape, with fairly smooth surfaces," giving a value of 1 for S; the viscosity of the oil is 225 Saybolt-Furol, or approximately 56 Engler, and the average climatic conditions are moderate to cold, which by referring to the chart Fig. 1 gives a value of 1.05 for F.

The formula thus becomes

$$P=1.15\times 1\times 1.05\times 4.33,$$

indicating 5.2 percent of oil to be added to the aggregate. The dry aggregate shows a void content of 20 per cent. Converting the 5.2 percent of oil by weight to terms of percent by volume, we have $2.65\times 5.2\div 0.97$, or 14.2 percent. Since after subtracting 14.2 from 20 percent the remaining voids are less than 12 percent, no void correction is necessary and the proper percentage of oil to be added remains at 5.2 percent.

Conclusion.

The tables and charts giving the values of the various coefficients are based upon average experience with the materials available, and some are, of course, subject to correction and refinement. It is the writer's desire to invite discussions as to possible refinement and to additional values for other materials. It is thought, however, that the formula advanced is correct in its basic terms and should offer a foundation for the development of more exact theory of design.

The fourth group the literature seems to divide into would be the Analysis of the Road Surface as a Structure. This particular group of papers seems to be best represented by a paper by Mr. H. G. Nevitt, manager, Road Oil and Asphalt Department of the Socony-Vacuum Oil Co., White Eagle Division, in which he presents "The Structural Comparison of Road Surfacing Types."

The author briefly summarizes the stress analysis and design of fundamental road surfaces, differentiates the usual forms of treated aggregate surfaces into two types, "flexible" and "semi-flexible." He contends that the "semi-flexible" type of pavement surface combines the advantages of both the rigid slab and the flexible surface types, by utilizing the beam stress distributing action of the rigid slab and the subgrade support of the flexible type. The author also states that the semi-flexible type may be designed and develops a formula for a rational design.

TABLE I—COMPARISON OF RESULTS OBTAINED BY FIVE ROAD-OIL FORMULAE

Total Percentage of Aggregate Passing

Sample	1 in.	¾ in.	¼ in.	10 m.	20 m.	30 m.	40 m.	50 m.	100 m.	200 m.
105	100.0	93.4	76.7	49.5	40.8	34.7	31.5	27.6	18.5	10.1
106	....	....	....	100.0	98.1	93.3	89.2	82.2	55.6	43.8
113	....	100.0	97.0	79.7	48.5	29.0	21.2	14.4	6.8	3.9

Oil Percentages Indicated by Various Formulae

	McK-F.	Utah	Wyoming	Idaho Curve	New Mexico
105	3.657	4.278	5.119	4.8	5.365
106	9.132	10.396	12.785	Unobtainable	12.748
113	3.242	3.667	4.539	Unobtainable	3.459

TABLE II—VALUES OF THE MATERIAL

COEFFICIENT M

Material	Value of M
Quartz or sand, particles uncoated	1.00
Siliceous material, portion of particles	1.05
Decomposed granite	1.10
Sand, particles moderately coated	1.15
Feldspar	1.10-1.15
Sand, particles highly coated	1.30
Limestone, average	1.30
Lava and other porous material	1.50 and up

TABLE III—VALUES OF THE WEIGHT

COEFFICIENT W

	Specific Gravity of Dry Aggregate							
Spr. Gr. of Oil	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
0.93	1.02	1.00	0.98	0.96	0.94	0.92	0.91	0.89
0.95	1.04	1.02	1.00	0.98	0.96	0.94	0.93	0.91
0.97	1.06	1.04	1.02	1.00	0.98	0.96	0.95	0.93
0.99	1.08	1.06	1.04	1.02	1.00	0.98	0.97	0.95
1.01	1.10	1.08	1.06	1.04	1.02	1.00	0.99	0.97
1.03	1.12	1.10	1.08	1.06	1.04	1.02	1.01	0.99
1.05	1.14	1.12	1.10	1.08	1.06	1.04	1.02	1.00
1.07	1.16	1.14	1.12	1.10	1.08	1.06	1.04	1.02
1.09	1.19	1.16	1.14	1.12	1.10	1.08	1.06	1.04
1.11	1.21	1.18	1.16	1.14	1.12	1.10	1.08	1.06

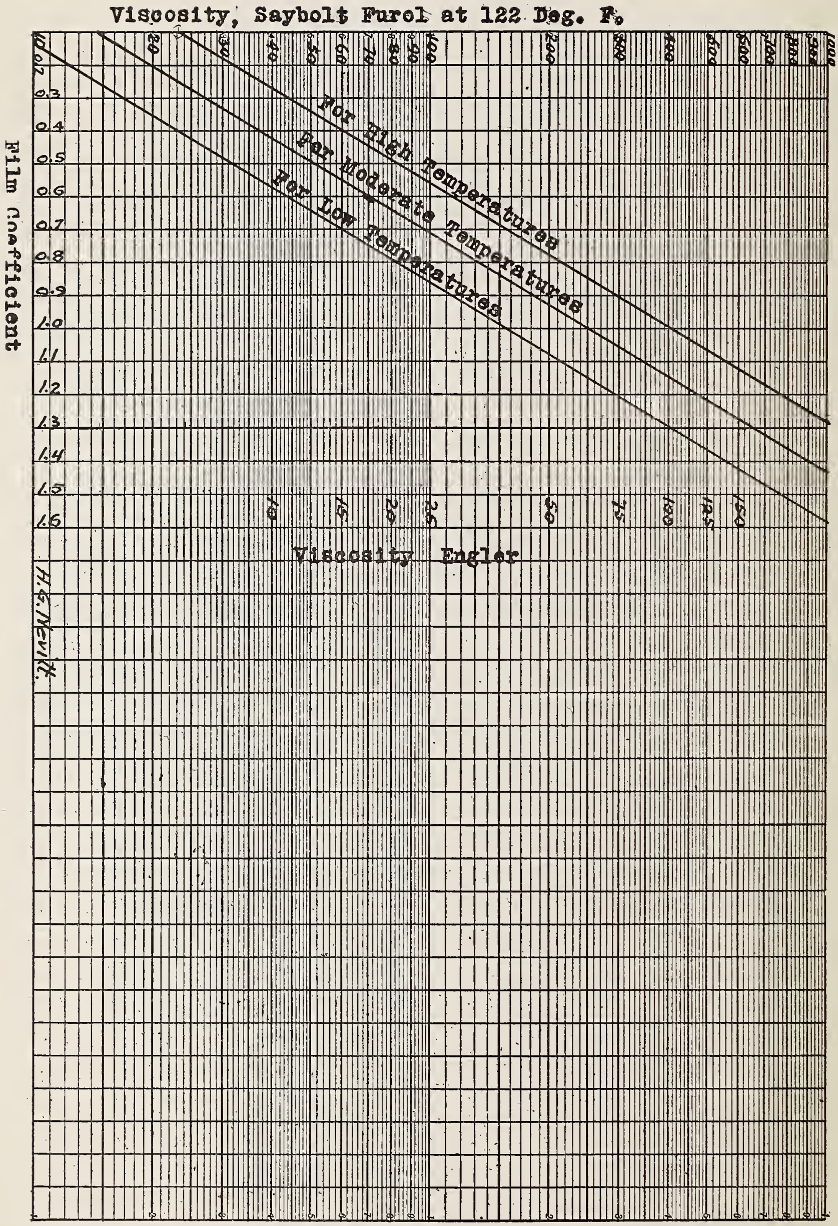
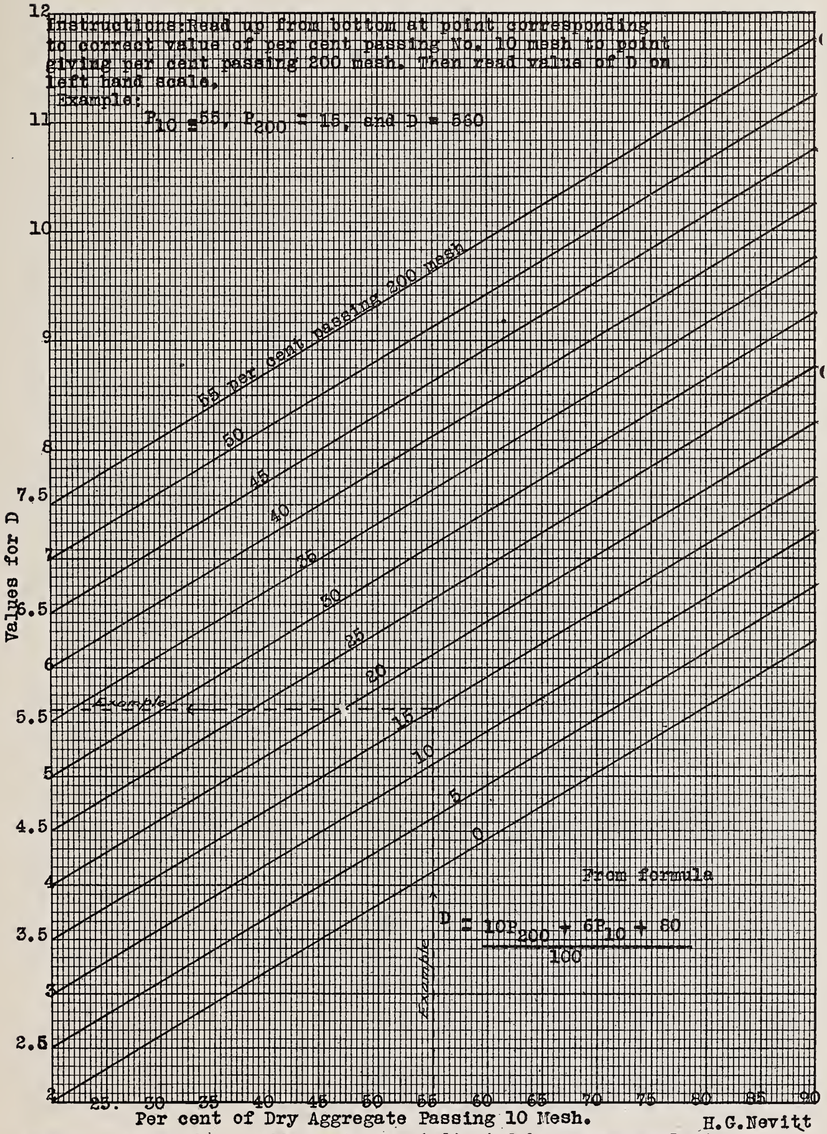


Fig. 1, Variation in Film Coefficient (F) with Oil Viscosity.



Instructions:Read up from bottom at point corresponding to correct value of per cent passing No. 10 mesh to point giving per cent passing 200 mesh. Then read value of D on left hand scale.

Example:

$P_{10} = 55$, $P_{200} = 15$, and $D = 560$

From formula

$$D = \frac{10P_{200} + 6P_{10} + 80}{100}$$

H.G.Nevitt

Fig. 2, Values for Coefficient D as indicated by screen analysis.

The author states that for the proper functioning of the "semi-flexible" surface, the asphalt or binding cement must have a high tensile strength.

Mr. Nevitt in another Technical Bulletin entitled "Ductility of Asphalts and Plastics" describes a method of determining the tensile strength of asphalts based on results obtained by the present ductility tests.

His bulletin may be briefly summarized as follows:

1. The three fundamental types of highway surfacings, the rigid slab, the flexible surface, and the semi-flexible surface are compared. The stresses involved and the resulting demands on the materials are analyzed and comparison of the claimed advantages and disadvantages of the three types are clearly stated.
2. The author states that the "semi-flexible" type offers great advantages for the majority of highway demands and expresses his belief that the full possibilities of this semi-flexible surface is not widely appreciated.
3. The article clearly states that in addition to the usual design requirements, the semi-flexible type surfacing demands a high tensile strength binder or cement.
4. The author also calls attention to the desirability for further research and analysis to assure the complete benefits possible from the use of the semi-flexible type of surfacing.

Mr. Nevitt ends the discussion with the following paragraph:

"It is believed that the potential advantages of the type, both structurally and economically, are so great that highway engineers should give this subject the closest possible attention. Equations, test data, etc., are readily obtainable for the type and its modifications. We already have a tremendous use of dynamically rigid mats, but this can be further increased and the economies already observed with this type further extended by the application of rational methods of design and material control."

The author gives in detail the computations to determine the required thickness of pavement, under assumed conditions of traffic, loading, and sub-grade, for the Rigid type, the Flexible type, and the Semi-flexible type.

The formula used by Mr. Nevitt to determine the thickness of the Rigid type (Concrete Slab) is as follows:

$$d'' = \left(\frac{1.92\ W}{F}\right)^{1/2} \qquad (1)$$

In this equation "d" is the thickness of the slab in inches at the center of the slab; 1.92 is a constant; W is maximum wheel load in pounds; and F is the allowable unit stress in the concrete. This equation is of the same form as that derived by Mr. Clifford Older.

Based on the assumptions made by Mr. Nevitt, he obtains the following:

$$d=\left(\frac{1.92 \times 9000}{398}\right)^{1/2}=6.59''$$

This thickness of slab, Mr. Nevitt states, corresponds to about a 9″ - 6″ - 9″ thickened edge section.

The thickness of the Flexible type pavement, Mr. Nevitt states, is based on a formula presented by Gray in a paper, "Design and Construction of Bituminous Pavements." This formula is:

$$d=0.S64\left(\frac{W}{S}\right)^{1/2}-e \qquad (2)$$

This formula is based on the assumption that the cone of distributed stress has a radius e at the surface and spreads at an angle of 45 degrees, so at the depth d, the area of the distributed stress is a circle of radius (e+d). The load W is resisted by the sub-grade reaction S acting over the area of the larger circle.

$$d=0.564\left(\frac{9000}{25}\right)^{1/2}-4\text{-}9=5.8''$$

The formula for the thickness of the Semi-flexible type (Mixed bituminous mat) is derived by Mr. Nevitt. The derivation of the formula is presented in the appendix to his very excellent paper.

The following is quoted from Mr. Nevitt's bulletin:

"(3) **Semi-Flexible Type** (Mixed bituminous mat) 24 feet wide.

The load will be carried by two resistances. First is the soil bearing power. The load supported by this will be

$$Ws=3.14\ S\ (d+e)^2 \qquad (3)$$

The additional load will be assumed supported by an annular ring of soil support reaction, the inner diameter of which will be the outer circle of the area of direct support assumed by the preceding formula, while the outer diameter is that necessary to give a total supporting area which will equal the load at the soil bearing reaction intensity. The formula derived in the appendix for the depth required with both these load resistances is:

$$d=0.564\left(\frac{W}{S\ 1.15\ (Sf)^{1/2}}\right)^{1/2}-\frac{e}{2} \qquad (4)$$

All the quantities in this equation are known from our previous computations except the modulus of rupture f. A cutback asphalt, drying to a semi-solid residue in a reasonable period, will be assumed used in the bituminous treatment, and the strength corresponding to f will be that for an asphaltic concrete. Since present usual methods of testing briquettes made from asphalt and aggregate result in more or less ductile yielding, the values they show will be lower than actually exist. The correct value will be found under proper test conditions for determining f as defined and discussed in this article. Since present results, under conditions minimizing the ductility effect, indicate about the same value for f (which is really dependent upon the tensile strength of the material) as for Portland cement concrete, it is anticipated that the value of 700 used for the rigid slab design will be found justified for semi-flexible mats by actual tests on materials specified for the purpose in accordance with the requirements outlined in the accompanying paper on the ductility test for bituminous materials (3). Since the comparison being made is not intended to indicate anything other than the possibilities of design in the three types of surfacing. This figure should probably be used, but to keep the comparison from being too sensational a value 400 lbs. per sq. inch will be assumed.

The remaining point to be decided is the factor of safety to use. In the rigid slab design this had two functions. First it indicated the margin of safety against immediate failure due to errors in the assumptions made as to loading, design, etc. Second it indicated the probable life before failure under the specified loading occurred from fatigue effects. Since the bituminous binders are not crystalline materials, nor have crystalline characteristics involved in their assumed action in this design, we seem justified in ignoring any allowance for fatigue. Consequently we need only a factor of safety against failure from unanticipated loading, etc. Strictly, since such surfacings are self-healing both by definition and in fact, no factor of safety, or a much less one than required for rigid slabs (which once cracked remain so) seems indicated. To hold to conservatism, the same factor of safety as was adopted for the rigid slab, namely 1.76, will be taken and the value of f substituted in the formula is properly, for our assumptions

$$\frac{400}{1.76} = 227 \text{ lb. sq. inch.}$$

We can solve for d in the formula (See Appendix)

$$d = 0.564 \sqrt{\frac{9{,}000}{25 + 1.15\,(25 \times 227)^{\frac{1}{2}}}} - \frac{4.9}{2}$$

$$= 0.564 \sqrt{\frac{9{,}000}{25 + 86.6}} \qquad 2.45$$

$$= 0.564 \times 9.00 - 2.45 = 5.08 - 2.45 = 2.63''$$

Actually this thickness will support 10,930 lbs., if the direct support from the subgrade, and that from beam action, are figured separately according to the method outlined in deriving the formula given in the appendix: 44% of the load is carried directly, 56% by ductile beam action.

Comparing the results for the effective depth of the three types of surfacing, we have values of 6.59″ for the rigid slab, 5.80″ for the flexible mat, and 2.89″ for the semi-flexible mat, if the assumptions made are correct. The possibilities of the semi-flexible type of surfacing seem rather remarkable from these figures, though readily understandable when it is realized that it has the benefits of the sub-soil support given the flexible type plus those of the rigid slab of extending the area of support.

This brief review and outline of our present knowledge and present method of designing leads me to the next thought I want to present, and that is the Research Idea as applied to our bituminous roads. I think you will all agree with me that Research is desirable:

First, to supply constants for analytical formulae necessary for proper engineering design.

Second, to enable us to obtain empirical solutions of problems until such time as they may be developed analytically.

You will say there has been a lot of research. We have had a lot of research and the past research has been very valuable, but more of the work performed in the past would be of more value if the research data were correlated with conclusions based on known conditions.

Many articles along the research line have been published that describe the methods employed and the results obtained, but they do not state conclusions.

It seems to me that there is a real need, an Ideal—if you want to call it that—an Ideal Plan of Research, well coordinated. With that thought in mind, I wondered who would be the best, or certainly one of the best, authorities to state what an Ideal Research Program might be and I wrote to Mr. Roy W. Crum, Director, Highway Research Board. Mr. Crum answered my letter under date of June 26. He says:

The Research Problem

"One of the greatest needs at the present time is for some agency to outline and plan the needed research work along these lines so that the problems can be attacked along coordinated lines. Practically all of the states that have any laboratory facilities at all have signified their willingness to cooperate in solving these problems and I think that is one of the ways in which the states can be most helpful, that is, in conducting laboratory experiments coordinated with those of the other states.

"The Highway Research Board has a committee which has just been organized under the chairmanship of Mr. Kelly of the Bureau of Public Roads with these objectives in mind. One of the most useful functions of the Highway Research Board is to serve as a clearing house for research information and one of the best ways in which the states can cooperate with us and with other states is to furnish us with information on all their experimental work so that we can make it available to those working in other places."

HIGHWAY RESEARCH BOARD

Prospectus of a Project on Correlation of Chemical and Physical Characteristics of Asphaltic Road Materials with Service Behavior of Roads

There is a great need for a fact-finding investigation to show the relations of the characteristics of asphaltic materials to the service records of road surfaces in which they are used.

The primary objective of such an investigation would be the acquisition of information upon which more rational specifications and methods for use of these materials could be based.

The Problem

The specifications in use for asphaltic materials are not satisfactory for the reason that they do not depend upon characteristics of known relation to service behavior of road surfaces. They have always depended upon tests for identification of certain properties or constituents. There are two kinds of identification tests that may be used. One is intended to identify certain properties which asphalts that have given satisfactory service are known to possess; the other is for the purpose of controlling the source of the material or its treatment during production. The first type has a valid place in practice, but as yet our knowledge in this respect is inadequate. The development of more rational specifications for asphaltic materials requires greater knowledge of the relations of identifiable characteristics to service behavior than we now have. The only excuse for the second type of identification tests is the lack of quality requirements that will assure satisfactory results. It is lamentable that our knowledge of asphalt and its use is still in such a state that many engineers feel that they must rely upon restrictive methods. It is not good engineering to be unable to use the most available material of satisfactory quality; and it is not good business to restrict competition when, by so doing, good materials are excluded.

Determinative tests that directly measure properties that affect the serviceability of asphaltic road surfaces are lacking, and to devise them will require research along entirely new lines. For instance, an accelerated test for the weathering characteristics of various kinds of asphaltic materials and research into the exact way in which asphalt performs its function of holding the aggregates together against the forces of nature and the loads imposed by vehicles should indicate tests directly related to this function.

The fact that asphalt technologists have been struggling with this problem for half a century demonstrates that the solution is far from easy. It is indeed a most complicated and intricate affair, but we are not ready to concede that it is unsolvable.

Examination of the record is an essential preliminary to further development of specifications or to further research work on unknown or not understood factors. Study of the causes of failure as well as reasons for success should be illuminating.

Information must be studied concerning not only the asphalts used, but all other materials and other factors of significance concerning service behavior.

As a corollary to the examination of existing roads, data should be accumulated concerning roads under construction, with detailed information concerning the materials used in them. The effects of construction operations upon the characteristics of the material should be investigated. It is probable that the field observations will lead to further laboratory research and perhaps to the development of entirely new tests.

Cooperating Agencies

In order to reach worthwhile conclusions it will be necessary to have the sincere cooperation of the U. S. Bureau of Public Roads, the State Highway departments, many city engineering departments, and the producers of asphalt and other materials. In particular the investigation cannot succeed without the whole-hearted technical support of the producers of asphalt.

Procedure

To reach the objective of developing information from which rational specifications for asphaltic materials can be formulated, an extensive investigation must be carried on, and to do it in a reasonable time a considerable technical staff will ultimately be needed. It is proposed, however, that a year of exploratory work be carried on in order to get the objectives more clearly defined and to organize the larger program in an effective manner. Someone should be employed for this preliminary work who will be competent to take charge of the complete investigation, the compilation and study of the data and the preparation of the reports.

The work should be supervised throughout by a small committee of the most competent asphalt and paving technologists in the country, representing both consuming and producing interests. Proper balance between interests should be maintained so that results strictly scientific and impartial in character will be secured.

The year of exploratory work should comprise examinations of considerable mileages of existing roads, the conditions of which can be correlated with the characteristics of the materials used in them, and preliminary laboratory studies looking toward the development of new methods of measuring such characteristics of asphalts as durability, stickiness and consistency.

Although on the field survey it will be the case in many instances that usable information concerning the materials is lacking, if enough cases are examined it is probable that an adequate number with significant data will be found. It will therefore be necessary to make thorough search for existing roads on which data concerning the materials are available.

Following the completion of this preliminary work it would be the duty of the supervisory committee to study the reports and the accumulated information and to plan the further work that will probably be needed on a more extensive scale extending over a term of years to attain the objectives of more rational specifications for and use of asphaltic materials.

It is impractical to attempt in advance of the preliminary work to lay out the details of organization and procedure for the larger project, although presumably continued field survey work closely correlated with laboratory research will be needed. It may be found desirable to set up regional committees to guide the work geographically or committees on different types of construction for functional guidance.

A competent research asphalt technologist should be employed to assist the committee in planning procedure, to conduct the field surveys and to prepare reports for the consideration of the committee.

It is expected that in the various states visited in the course of the survey, additional observers and transportation facilities can be arranged by cooperation with the state highway departments.

It is also anticipated that laboratories of the Federal Government, including the Bureau of Public Roads, Bureau of Mines, the State Highway departments and many colleges of engineering will cooperate in attacking the problem along lines suggested by the committee.

Exploration of the Problem. One Year's Work

The objectives of the year of preliminary work shall be to collect basic information concerning some types of surfaces and materials, and complete the analysis of the problem and learn how to break down the larger job into work units so that complete plans for the investigation can be drawn. It is expected that these objectives can be attained through field surveys supplemented by laboratory experiments.

It is obvious, from a glance at the classification of road types and materials, that any attempt to study all phases of the problem during the first year could not result in the acquisition of enough data respecting any one type of construction or material to be conclusive in any direction.

It is thought better, therefore, to restrict the first year's work to considerations of one type of road or one type of material.

Having in mind that the preliminary work should yield comprehensive information about the nature of the problem and the conditions to be encountered throughout the country, it appears that the most suitable prospect for securing these results, as well as facts about the materials are covered in Sections 1 and 2 of the Classification.

It is, therefore, proposed that the first year's field work consist of intensive study of examples, both good and bad, of both close graded and open types of road mixtures using liquid asphalts (slow curing oil, cutbacks and emulsions) in those localities where the typical combinations with materials from all of the different sources can be best examined. Also, during this year, cooperative laboratory research should be initiated.

Although it would probably not be possible to work in each state, the use of these combinations is so widespread that some results of importance to every locality should be secured.

Highway Research Board

CLASSIFICATION OF ROAD TYPES AND ASPHALTIC MATERIALS

1—Liquid Asphalt Road Material, close graded mixture, so-called Western type:

Asphaltic Materials—
- (a) Slow curing oils
- (b) Cutback asphalt
- (c) Medium curing kerosene cutback asphalts
- (d) Powdered asphalt

Probable Sources of Crude Oil—
- (a) Mexican field
- (b) Mid-continent and Rocky Mountain fields
- (c) California field

Area of Use—Everywhere west of the Mississippi river, except Texas, Oklahoma and Arkansas. Also used to some extent in Florida and South Carolina.

2—Liquid Asphalt Road Material, open graded, so-called Retread type:

Asphaltic Materials—
- (a) Cutback asphalt
- (b) Emulsions
- (c) Powdered asphalt

Probable Sources of Crude Oil—
- (a) Mexican
- (b) Mid-continent
- (c) Venzuelean
- (d) Californian
- (e) Colombian

Area of Use—Generally east of Mississippi river. Typically developed in Indiana, Ohio and Kentucky.

3—Bituminous Penetration Macadam:

Asphaltic Materials—
- (a) Hot asphalt cement
- (b) Emulsion

Probable Sources of Crude Oil—
- (a) Mexican
- (b) Mid-continent
- (c) Venzuelean
- (d) Californian
- (e) Colombian

Area of Use—Northeastern region. Principally developed in Rhode Island, Massachusetts, Connecticut, New York, Pennsylvania.

4—Asphaltic Concrete:

Asphaltic Materials—
- (a) Asphalt cement

Sources of Crude Oil or Native Asphalt—
All crude oil sources and Trinidad and Bermudez Lakes.

Area of Use—General. Particularly extensive use in Pacific Coast states and east of the Mississippi river. Also in cities generally.

5—Sheet Asphalt:

Asphaltic Materials—
- (a) Asphaltic cement

Sources of Crude Oil and Native Asphalt—
All sources

Area of Use—General, principally in cities.

NOTES—1. The asphalts in any of the classifications may be produced by the cracking process, and as the relation between this process and road making quality is a subject of controversy, this detail should be checked in all cases by refinery information or records of the Oliensis test or both, if possible.

2. The patented types of premixed cold-handled mixtures occur in various classifications and would be studied in those relations.

Under the general heading "Exploration of the Problem," Mr. Crum outlines a year's work.

This outline looks like a tremendous amount of work. It is. It is an ideal set-up. If the state had a well organized Research program, coordinated through the National Research Board, the year's outline would not look so big. Many of the states are carrying on duplicate investigations with no contact with their neighbor who is interested in the same or similar problems. This Conference group should study and outline a Research program, a well coordinated program, functioning through the National Research Board as the clearing house.

CONFERENCE ON REVIEW OF ANALYTICAL ENGINEERING METHODS AND RESEARCH AS APPLIED TO BITUMINOUS CONSTRUCTION

CONFERENCE BOARD

PROFESSOR L. D. CONKLING, Chairman,
Montana State College, Civil Engineering Department

PROFESSOR R. A. MOYER,
Associate Professor Highway Engineering, Iowa State College

J. E. BUCHANAN,
Testing Engineer, Idaho Department of Public Works

E. B. HOUSE,
Dean of Engineering, Colorado State College

W. M. COBLEIGH,
Dean of Engineering, Montana State College

Prof. Conkling: Gentlemen, the meeting is in your hands; the success of it depends entirely upon you and the discussion that you will start. Just to start something I would like to make this statement; maybe you will agree with me, maybe you won't, that we can't have a pavement if we don't have a foundation. I think probably more construction men are here present than research men. The construction man goes out and builds a road; he builds a good road; sometimes he doesn't know why, but it is good, and he remembers it and thinks what a fellow he is, but the failures he tries to forget. Now, why shouldn't the construction man really study the failures more than he does; that is research. Study it from the bottom up, know what he put in, why he put it in, and how he put it in. Study and thought are required to correlate these facts. We have thousands of miles of roads that have been completed and if we could go out and go over those roads and had a real record of what occurred when that road was constructed we could draw some mighty fine conclusions from our observations.

How many of you people really agree with the idea that a road is a structure and that it can be designed just as much as any structure can and that we should not go about it hit or miss as we have done in the past. I think it can be done, but how about you? Mr. Nevitt, I am going to pick on you because you are sitting over there where I can see you.

Mr. Nevitt:
Sacony
Missouri

I have always thought, of course, that we could design roads as a structure. I have in mind the history of almost every other type of structure. Bridges are the easy and outstanding example. We have the simple bridge, a linkage structure, which can be analyzed by simple mechanics, according to the loads expected to be carried and which has been very satisfactorily designed on that basis.

Every engineer who has been engaged in bridge work knows that the bridges which we build today are based on approximate design using simplifying assumptions. Take a bridge with pins, supposed to make it an ideal structure. That bridge never did actually function as a simple structure. But, we could make assumptions of that sort and get some sort of design. We had to allow for the errors of design; they were almost correct but they were not quite correct. We could design a simple bridge and we did, and for years that was the only type of design. Bridges are designed by far more complex and complicated methods than the simple structure method. We get into the theories of elasticity and other complicated formulae. We do not have to do that to build most of these bridges but we have refined the design so as to do so more economically. We had to use the simple bridge design to start out with because we had to figure some way to get our bridge design within reason. We first had the simple structure;

now today we have very complex methods of design. So I am very much convinced that the road which is a structure can be similarly designed by rational methods. It is a very different type of structure, quite a little different, if you get down into the fundamentals of earth action because our final support of the road is the soil. But why can't we start off with some simple assumptions, taking care of the uncertainties with good factors of safety. We know that our assumptions are not absolutely correct; they are merely simplifying ones which suit available conditions. Soils possess rather complex properties, such as elasticity and plasticity. To exactly define the bearing power of a soil may be difficult, but we should be able to say that the soil under a road, under its worst conditions, uniformly exhibits a certain bearing power which may be used in road design equations. In the final analysis the equation may be the basis of the bearing power definition. Nevertheless through such concepts and simple equations we should be able to design bituminous surfaces more uniformly and exactly.

I am very much sold on the idea of trying to start such a method of attack on road structure. I do think that we can write formulae and develop methods that you can use tomorrow, but why not start to do the things in a logical way.

I believe something like that can be done which can gradually be developed into a rational or real engineering method of design, rather than the result of experience which is pretty much what we are working on today in considering the road as a structure.

Prof. Conkling: Might we have something from the floor other than what Mr. Nevitt has said? Can't we get an argument or do you all agree?

Mr. Nevitt:
Sacony
Missouri

What do you gentlemen from the colleges say?

Prof. House:
Colorado

Well, the only thing I have to say is to question the assumptions the gentleman has just spoken of,—they are seldom correct. The soil which constitutes the foundation of the road varies so that assumptions which might prove correct in one locality might be entirely wrong in another. If things were just constant we would be all right. But they are variable and as far as my experience goes they are really variable. It makes our assumptions very doubtful in a great many instances.

We have just completed a survey of the conditions of the oiled-gravel roads of Colorado and we have found out some very pertinent facts I think. We went onto these roads and took samples. We took samples where the roads were failing, we took samples where the roads were holding well. We found that in many instances, a great many instances, the road had the same oil content where they were failing and where they were standing up as they should. We made mechanical analysis of the aggregate that made up the matt of those road surfaces. We found that they varied very much. In fact the aggregate had probably been selected because it was the most available aggregate and it had been taken because of economical considerations rather than the fact that it was or was not a proper aggregate for the oiled matrix.

We found that the percentage of oil which would make good roads varied all the way from about 3% to 6% or more. There is a big latitude for the oil content.

We analyzed the sub-grade for its water content and also its mechanical analysis and we found that when we had the poor road surface we usually had a sub-grade that contained rather a high percent of water. There is a relation between a wet sub-grade and a failing surface. Just what the relation is we are not able to tell you at the present time. Just what the effect moisture in the sub-grade has on the oil in the matrix we don't know, but there is some relation between a wet sub-grade and the failing surface. With an oil content that is too low we have the ravelling road surface. With an oil content that is too high or with an oil content that is right and a wet sub-grade we have rolling and rutting and also alligator cracking.

I think that in order to build a structure we must make the simple assumptions but we must be sure that those assumptions are pretty nearly correct, if not the design of the structure is going to be wrong and it will be like the engineer who misplaced his decimal point on his bridge figures and when the train passed over, with the crowd that was there at the opening, and the bridge failed, he turned to his friend and said, "There's that damn decimal point."

Mr. Stoddard: Iowa — I would like to ask you. In connection with the surveys that have been made in Colorado surfaces, were those surfaces made with the same general thickness or had any attempt been made in their construction to vary the thickness with the condition of the sub-grade?

Prof. House: Colorado — The matter of records of the things that occurred during construction were not obtainable; the consequence is that I can't tell you. The thickness of the matrix was about the same at all places. Does that answer your question?

Mr. Stoddard: Iowa — I was wondering if there were any variations of thickness of the base in connection with the thickness of the surface.

Prof. House: Colorado — No. Of course all the roads before the oiled gravel was applied, were surveyed and surfaced and then the oiled gravel applied in the usual way by spreading the aggregate, distributing the oil and mixing with the blade machine. That was the general procedure which was followed. I do not think that it is possible to get a uniform oil content in a road surface where the oil is applied with the ordinary distributor and then mixed with the blade.

Prof. Lang: Minnesota — It might not be amiss for me to mention at this time that we have two papers in the section on Fundamentals; one paper prepared by the Kansas Highway Commission on the preparation of natural soil and the other by Mr. Stoddard who just spoke, on the gravel bases, and those papers have reviewed, I think, the design idea, as well as that can be developed at the present time. I don't wish to stop any discussion this morning, but I just don't like to see any conflictions in the discussions.

Prof. Conkling: Montana — Thank you. I started this with the particular idea that I wanted to bring out the fact that there is need for further research along these lines. Do we want to say we can't do anything? No. We want more and better research. That is the particular thing I am hammering on at the present time. In connection with the research we are primarily an engineering group, but we, as engineers, cannot succeed without calling in the help of the other people, the other scientists, if you want to call it that, and I would like to ask Dean Cobleigh, of Montana State College, to make suggestions in regard to research problems from the standpoint of Chemical Engineering.

Dean Cobleigh: Montana — In discussing the research problems of bituminous road construction, the chemical engineer is chiefly interested in the chemical and physical properties of the materials that are specified in the design of the bituminous road surface. I can see plainly, from the previous discussions, that it is desirable to consider bituminous road design as a problem of structural engineering. However, there is one point in the design of a bituminous road surface that differs from a structural design such as that of a bridge.

In the construction of a bridge, the materials specified by the engineer are fabricated in factories. The iron and steel and other materials used in the structure are produced under factory control. This insures structural materials of known physical constants.

Bituminous road surfaces, on the other hand, are produced in the field and chemical and physical changes occur during the processes of mixing and curing. These changes are not always the same, due to a number of variables, even when the aggregate is carefully specified and the constants of the road oil are known because the oil is produced under controlled factory procedures.

It follows that the preparation of a bituminous surface represents a production process which, under field conditions, is not subject to as accurate control as the factory production of regular structural materials such as iron and steel. Naturally, the engineer cannot predict the final character and properties of a bituminous road surface with the same certainty as in the case of a bridge structure.

More to the point, however, I was requested to suggest research problems from the standpoint of chemical engineering. From a limited experience, I am not able, with any degree of assurance, to suggest original problems. However, I have consulted considerable literature and I find that there are many research problems in which the chemical engineer and the chemist might make profitable contributions. I am quoting an abstract in the April 1, 1936, Quarterly Digest of Current Asphalt Literature, published by the Asphalt Institute. The original paper was published in "Better Roads" and was entitled, "Needed Research Work on Asphalt Road Materials" by E. F. Kelley, Chief, Division of Tests, U. S. Bureau of Public Roads:

"The chemical composition of asphaltic materials is varied and complex, resulting from the use of different crude materials and different methods of refining. A realization has developed that our present knowledge of how the performance of asphaltic materials is affected by their varying characteristics is not satisfactory. From the standpoint of quality the essential characteristics of the asphaltic mixtures for road building are ability to coat the particles of mineral aggregate, to adhere to them and bind them firmly together, resisting the disintegrating action of elements. Some of the actual tests of asphalt attempt to measure certain qualities directly, others are identification tests intended to require the use of certain materials having previously given satisfaction. Research indicating how the characteristics of crude oils influence the qualities of the finished product is needed. Some cracked materials have been unsatisfactory and some entirely satisfactory for use in certain types of paving; there has been a general tendency to discriminate against the whole group. Research that will correct this situation is of the utmost importance. Experience and research have shown that heating, mixing and placing asphaltic paving mixtures may alter the characteristics of the asphalt. The results of a few tests recently made in the laboratories of the Bureau of Public Roads illustrate the changes that prolonged heating may cause in asphaltic materials. A study of the interrelation existing between asphalt and the mineral aggregate with which it is combined is very important. Promising results have been obtained in the utilization of liquid bitumens in stabilizing of soils for base courses. This work would possibly create a market for petroleum products unsuited for other road work."

The problems here suggested indicate that the research committee will discover many problems, some of which will be of such a nature that various branches of engineering and science can make effective contributions.

Mr. Kirby: Utah

I am wondering if the men present who are engaged purely in chemical work could not meet as a group during these meetings to discuss purely chemical problems and testing technique as applied to the laboratory side of asphalts.

Prof. Conkling: I think that is a very fine thought and your point is very well taken. Possibly in the future this might grow into sections where the people interested in any line could get together and discuss in their own language points in which they are particularly interested, and not let that in any way detract from the purpose of the general gathering and discussion.

Prof. Lang: Minnesota

We have had prepared for this afternoon's session a paper on the Characteristics of Asphaltic Material. If the chemist wishes to read that over, we will be glad to listen to some discussions this afternoon.

Prof. Conkling: I think we are all interested in the general problem and I believe Professor Lang will allow us to discuss this idea, even though we do get into some of the other papers. How about it, Professor?

Prof. Lang: Minnesota

All right, go ahead.

Mr. Benedict: B. P. R.

I should like to second Dean Cobleigh's suggestion for research into the affinities between asphaltic products and mineral aggregate, which is in the chemical field, and we certainly need it. However, findings in research should be expressed as far as possible in terms of the physical result rather than in highly technical terms which mystify the field men. Research work will not succeed in its purpose unless we receive the cooperation of the construction men, so let's remove the "mystery" from our findings.

Prof. Conkling: Mr. Buchanan, have you something that might help us along?

Mr. Buchanan: Idaho

Professor Conkling and Gentlemen: I don't want to get out of bounds with Professor Lang, but a suggestion was made this morning that was worth following. It was made by Professor Conkling in presenting his paper and concerned a bibliography of research. I wonder if there are not now reposing in files many papers containing bibliographies on many phases of this general subject. Further, there might even be extensive bibliographies. If we could follow the suggestion of collecting and publishing these, we would have one real accomplishment from this morning's meeting.

We cannot consider a bituminous mat without considering what is under it, which automatically brings supporting materials into the discussion. I find it difficult to consider base and surface separately as is often suggested or implied.

It seems that all of us are engaged in research of one kind or another, whether we work in laboratories, or whether we examine failures in the field. If we could collect the results of all these studies and record them in a comprehensive bibliography, we not only would have something concrete to work with, but also a very definite achievement to the credit of this meeting.

Prof. Moyer: Iowa

Mr. Conkling and Gentlemen: I received a rather generous letter from Mr. Cheney inviting me to attend this conference and also to take part in the program. I was impressed with the fact that presumably no place was given to my own specialty, that of "Skidding." I felt that the skidding problem was so important a factor in bituminous road construction that I was obliged to come out here and attend this conference. I wrote Mr. Cheney and informed him that I was not anxious for a spot on the program but would bring my skid-test exhibit which would tell its own story, and give you very easily the picture of the type of road surface which our test showed were most nearly non-skid. I have traveled about 2600 miles getting here, largely on the roads of Nebraska, Colorado, Utah, Idaho, Wyoming, and Montana. I thoroughly enjoyed the fine roads in these states. However, I was impressed with the fact that probably 20% of those roads might easily be considered as slippery when wet. There is no excuse for this slippery condition. I know, and you know, that oil or tar by itself is slippery. If there is an excess of oil on the surface, it is bound to be slippery. There is a simple way of eliminating the slipperiness: Eliminate the excess oil. I believe that you will notice in the exhibit which I have prepared in the back of the room, that the presence of excess oil or asphalt on the surface is the most common cause of a slippery surface when wet. I think that fact should be emphasized so that you will recognize it in all of your construction work. You can tell by its appearance when a road is slippery: it is a road which has a leathery texture or a glazed surface. Any road with a sand-paper like finish or the surface of which is covered with stone chips providing a gritty abrasive type of finish, is non-slippery. An important discovery which has come out of our research was to the effect that a bituminous road has in it properties which can make it the best non-skid road that has thus far been devised. This is contrary to the beliefs of the advocates of P. C. concrete or brick road construction. However, in this respect our results are rather convincing as the exhibit will show. In is our purpose to be impartial in our tests. For example, our road tests consistently show that fuel mileage on concrete is higher than that obtained on asphalt surfaces, possibly because asphalt surfaces are more flexible. During the past summer we have been running road tests in an attempt to correlate tire-wear and slipperiness. Tire-wear on bituminous surfaces can be quite variable. The tire-wear on a slippery glazed-over asphalt surface may be only one-tenth as much as on a rough-textured abrasive non-skid surface. Tire-wear is a real problem, but I believe safety is far more important. In other words, I would prefer to see asphalt surfaces built which are non-skid than to see surfaces built to economize in tire-wear at the expense of safety. After our road tests have been completed, we hope to be able to advise you how to provide a non-skid surface with a minimum amount of tire-wear.

Probably one of the most surprising features of our skid tests to me was that of finding out just how slippery black top roads can be! We ran tests on snow and ice. We ran tests on lake ice, sheer ice so smooth that I can't conceive of anything more slippery. Nevertheless, I want to tell you frankly that black top roads have been built and are still being built which are just as slippery when wet as that snow and ice. You should continually keep in mind that you will have a dangerously slippery surface if there is excess of asphalt that causes the road to be glazed-over. In many cases the non-skid surface can be built at a lower cost because there is an elimination of excess asphalt. I was particularly interested in the cover stone used in Yellowstone Park. In many cases it contained obsidium which was in the form of a hard abrasive type of rock crushed to sand size. In my opinion this should provide an excellent non-skid surface, typical of the type of sandpaper finish which I so strongly recommended in our exhibit.

Now I believe that it is the obligation of all men employed in the construction and maintenance of black top roads to see to it that these roads are kept in a non-skid condition. Just as you apply sand on a slippery icy or snowy surface in the winter time to provide traction and protection against skidding, in the same way you can provide protection against skidding on black top in the summer time when wet. Furthermore, by firmly imbedding the sand in the ice it is evident that the non-skid condition is improved; for the same reason it is important that the sand or stone chips be firmly imbedded in the asphalt surface by rolling and other means.

According to the reports I have had on this trip, a good deal of the rain we have had this summer has been out here in the west. We have had very little rain in Iowa this year although usually we have our share. This leads me to say that although a large mileage of black top in the western states is in dry territory, practically all of this mileage is subject to some rain and the obligation to build non-skid surfaces here is as great as it is in the states with greater rainfall. Personally, I believe there is no excuse for building a single mile of road which we know is certain to be slippery or which has the remotest chance of being slippery. One fatal accident is too great a price to pay in exchange for the possible saving in construction or maintenance costs realized by not using a non-skid treatment of sand or stone-chip cover material. Seal coats without cover material are rarely if ever satisfactory as a means of providing a non-skid surface. I strongly advise against the plain seal coat without cover material. The transition from the non-skid to the slippery condition may develop far more easily if the plain seal coat is used than if the proper amount of cover material is used. In any case, until we have provided a gritty surface finish or an sand-paperlike finish on every foot of highway, our obligation to provide a safe roadway for the driving public will not be realized.

Prof. Conkling: I think we should not overlook the fact that we will have a paper on Construction this afternoon. Professor Lang may object to this discussion.

Prof. Lang: Minn.

You are getting the wrong idea, I am just trying to get over the point that they should read the papers before the discussion starts this afternoon.

Prof. Conkling: For the construction and maintenance problem this afternoon I think Professor Moyer has some very valuable material. He has fulfilled my ideas of what I wanted of him by suggestions and implication that further research is necessary, so that if you will, just keep your suggestions until we have a chance to use Professor Moyer on the other papers.

Prof. Duff: Nebraska

I have not had time either to read the papers but I feel that there is one suggestion that Professor Conkling brought out at the beginning of this morning's session with reference to the need of research for developing tests that will determine the properties of the asphaltic material that effect its serviceability in the bituminous surface, and Professor Moyer's talk brings out more forcibly than ever this point in the glazed surfaces that we have in some of our roads.

A glazed surface may be due to excess oil, but I am rather inclined to believe from our experience in Nebraska that it is more often due to the type of oil rather than to the quantity of oil. A number of road oils have the property of forming a hard, glazed surface, due to oxidation, or some other change which takes place in the product. I think perhaps our chemist friends might come in and give us some help on this matter. A simple test should be developed that could be used to differentiate between the oils that have a tendency to produce a glazed surface and those oils which do not. Such a test would be of great help in the selection of an acceptable road oil. A glazed surface is very annoying in wet weather. I agree with Professor Moyer that it gets almost as slick as ice. The matter of differentiating between asphaltic products is not yet solved. In other words, we have no specifications at present that appear to be adequate for differentiating between the good and the bad oils or those that produce satisfactory surfaces and and those that produce unsatisfactory surfaces. We have the SC group of oils which may meet all the requirements of our present specifications and yet they have entirely different characteristics.

If the Oliensis test is not applied to the SC-1, 2 and 3 groups of road oils we may have, under our present SC specifications, two entirely different types of products which for some types of construction, will produce surfaces of entirely different characteristics or properties.

It may so happen that some refineries are unwittingly supplying poor oils and that they are not able to supply good oils under their present methods of operation but if their oils meet the required specifications they can hardly be criticized for supplying them. If we can find some way of setting up our specifications so that only the good oils with uniform and definite characteristics will be acceptable I doubt if the expense of producing such products would be much greater. Of course it would require some changes at some of the refineries. Many of the refineries make no effort to ascertain whether or not the product they are supplying is the best that can be produced. In many cases a slight change in the refining process would make an entirely different road oil. But do we have at the present time any group of engineers or technologists that are capable of telling the producers of road oils just what properties and characteristics are essential to produce a quality product.

Mr. Kelly of the Bureau of Public Roads at Washington objects, and rightfully so, to tests that merely control the source of the material with the idea in mind of shutting out certain products.

We do not know just what we want and since we do not have sufficient knowledge of the properties of certain products that are considered unsatisfactory we write in certain tests that may have no bearing on the quality of the product but which will eliminate the particular type of product that we do not want from some certain refinery and by so doing several good products from other sources may be excluded. We should have some quality tests and then make our specifications more definite in order to get only good products.

Dr. Loy: Wyo.

Mr. Chairman: I had hoped that my position in the oil industry would forbid me from participating in this discussion but Fate has decreed otherwise. The trend of the discussion this far, while it has been very enlightening, has been directed toward the old abhorrent idea that there is such a thing as a good road oil and a bad road oil. If I understand your attempt this morning, Professor Conkling, it is a plea that past experience and the practical research conducted by the engineers on the firing line should be compared with the theoretical investigations in the laboratory, and the two so coordinated that in the future we may arrive at a stage when the future engineer can go to the library, or museum if you prefer to call it that, and pull out from some pigeon-hole a formula with which help he can build a road which will not be subject to the vicissitudes and criticisms which we are leveling at the aggregate on the one hand and bituminous material on the other. To give an illustration of what I mean is that some of the most fundamental research work has been done some fifty years ago at Yale University and published in the Yale Quarterly at the time. It was resurrected some thirty-five years or thereabouts afterwards and constituted an important part of some of the underlying work done on physical chemistry and applies to many of the problems we are now trying to work out. It was called the Yale Sarcophagus because it had been buried in that place for so many years. As I interpret it, your desire, Professor Conkling, is to take the good research work that has been developed from practice as well as theory, and let us have it in pamphlet form so that it may be available to everybody, thereby, to serve for future use because now it is merely fragmentary information that different men have stored away, but is not available to the rest of us. Your plea is for some centralized agency to take upon itself the assembling of that material. Is that correct?

Prof. Conkling: Yes. That is correct.

Mr. Kushing: Michigan There has been a great deal said about the situation but nothing done about it. Very few important changes in the control testing of bituminous materials has been made for several years. The problem is serious and new workers in the field must be encouraged—prejudiced view points cannot be considered. I had an opportunity about two years ago to speak before the Fourth Annual Road Oil Congress at Tulsa in which I suggested to them that they emulate to some extent the activities of the Portland Cement Association. The Asphalt Institute is not giving to this group and other groups throughout the country what they ought to give us in the way of fundamental information. Research work performed by unrelated groups must be coordinated by some organization. A good deal of research is necessarily purely fundamental. If I am correct in my interpretation of good research, a man wants to obtain a definite answer. He makes his conclusions many times before he ever attempts the research work. We have too much of that type of research. What we need is a central organization to coordinate and correlate research, which gives definite and conclusive answers. An attempt was made by the Highway Research Board, and I don't know why they never followed it out, but if this conference could bring pressure to bear upon the Highway Research Board whereby this research information can come from that board, I think it would be a good idea.

Prof. Lang: Minn. I think I can answer that question as regards the Highway Research Board. The project they set up depended upon getting money from the industry, and the industry would not support the research projects. They have a committee of which you spoke this morning. That committee is to meet in Washington on the 21st of the month. If there are any suggestions, the committee will be glad to get them.

Prof. Conkling: We have evidently at least succeeded in starting some discussion. However, our time is drawing to a close. There are several announcements to make and at this time I am very glad to turn the meeting over to Mr. McKinnon.

Mr. McKinnon: It seems that the discussion this morning has brought out one or two very important things, one has been the coordinating of the research activities of the different states. It has further been brought out that the Highway Research Board has set up a project along these lines and that project has been delayed through lack of sufficient funds. It has been thought that there are possibilities along these lines from such a conference as this, or at least that some help in this matter could come out of such a conference as this. We should like to appoint a committee from those present who would meet and report back to this conference any suggestions they may have along the lines that have been brought out this morning. First, we would like to have the committee meet in Professor Lang's room, No. 254, immediately after this afternoon's session. We would like to have them organize and come back with a report. I am going to ask Professor Lang to act as temporary chairman of that committee and from the colleges and universities we would like to have:

Professor Duff of Nebraska
Professor Moyer of Iowa
Professor Conkling of Montana, and
Dean House of Colorado.

From the industry we would like to have:

Mr. Ramey of California
Mr. Gilmore of the Asphalt Institute
Mr. Nevitt of Missouri
Mr. Corbett of Montana
Dr. Loy of Wyoming.

From the engineering profession we would like to have:

Mr. McCoy of the Bureau of Public Roads
Mr. Raegel of Missouri
Mr. Powers of Arizona
Mr. Kushing of Michigan
Mr. Donohue of Montana.

This committee will report Thursday morning at the opening of the session with any recommendations they may have to offer.

THE NATIONAL HIGHWAY PROBLEM

By Honorable Burton K. Wheeler, Senior U. S. Senator from Montana.

Fellow Highwaymen,

Gentlemen: Dr. McGregor did not get that yet as he is a Scotchman and it takes a little time for a Scotchman to get it through him. I have been associated with a good many highwaymen but I never spoke to so large a group before. When they asked me to come and speak to you I said I did not know anything about roads. Dr. McGregor said, "We know you don't. That is why we want you there."

I have been interested in seeing good roads built in the United States. I have hesitated to talk about them because it seems to me that every time a politician is called upon to speak and he doesn't want to talk on some controversial subject that he gets up his talk about good roads.

I am not on the appropriations committee in the Senate which has to deal with the road building program, but I have endeavored to help and to assist Carl Hayden who handles the appropriations for the roads, public roads, and all other roads in the United States, and I just want to say that the people of the West and those who are interested in good roads are particularly fortunate in having as the Chairman of the Sub-Committee that handles these appropriations, the Senator from Arizona, Mr. Hayden, because if there is anybody in the United States that can get money out of the public treasury better than Carl Hayden I don't know who it is.

It is a difficult thing for you to get money for roads in this western country. Those of you who have had some experience in coming to Washington and asking for money will agree, I believe that at the present time we are governed by a situation where the eastern representatives from the large industrial areas and the large financial centers feel that the money that is being taken out of the treasury of the United States for roads in this western country is more or less money that is coming out of their pockets. Consequently, they are opposed to any great road program in the western states because they feel that it is money out of their own pockets. They don't seem to look at it from the standpoint of national welfare. The roads of the United States and the road program, in my humble judgment, have been great benefactors to all the people of this country wherever they may live. It is of great benefit because of the fact that some individuals may travel over the country and see the beauties of the various parks and the various different parts of the country. Some may take their vacations and get out in the open and travel by automobile, some can go from one particular section of the country and visit relatives or transact business.

If any of you happened to travel in various foreign countries you will appreciate what it means to have the people of one part of the country come in close contact with the people of the rest of the country. Recently, I had occasion to take a trip around the world and more recently I was in Europe. In Europe you have a group of small nations, many of them having an area no larger than that of some of the states in the United States. I just recently came from there and in each one of these various countries you saw them spending tremendous sums of money on munitions, you saw them preparing for another great world catastrophe and you saw them just wondering when it was going to break out and when they are going to have to send their children to be made into cannon fodder. The answer, in my judgment is quite simple. I have gone into France and talked with the French people. They don't want war. You can go across the line into Germany and talk with the German people. They don't want war. You can go into Italy and talk to the people, you can go among the Greeks, the Swedes, the Norwegians and the Danes and everywhere you find the same sentiment. Wherever you go you find exactly the same traits of human nature permeated by a great mass of people of those countries and the reason they have those wars is because of the fact that those people do not understand and do not come in contact with each other. It is because of the fact that they have built up nationalism and are taught to hate the people just across the border, but if they had roads and if they had closer means of communication and transportation they would break down the tariff barriers which keep those little states from coming in contact with one another and they could soon break down not only the desire for war but could make it impossible for the various little political leaders of those communities to go to war at all. It would be the greatest blessing that could come to mankind and Europe if it could come about, as it will eventually, that they will have these roads as we have here in the United States, connecting them so that the people will be able to break down the tariff barriers and all the other little barriers they have now so that they will be able to understand the people of the different countries as in the United States of America. If we had forty-eight different nations held apart by poor roads, held apart by poor means of transportation and poor means of communication and we had these tariff barriers between each one of these nations, war would be as rampant here in the United States of America as it is in Europe.

Then I go to China. I was in China a few years ago and had the pleasure of meeting Chiang Kai Shek, leader of the southern faction. I had the pleasure of talking to the northern general. I asked him, "Why don't you take the money you are spending building up your armies and spend it on good roads and on schools? If you did that rather than spend it on armies you would be doing a great service to your people." I am not going to tell you what his answer was except to tell me what a great civilization they had there a great many years ago, and it is true, and they could have a great civilization there today, if, instead of spending money on armaments they would spend it on roads and schools so that the Southern Chinese and the Northern Chinese would have a means of communication and would be able to come in contact from north, south, east and west.

What holds good in one of these countries holds good in each and every one in the world. Good roads, aside from the pleasure they give us for driving and aside from the pleasure which we get out of seeing the scenery, are one of the blessings to mankind, and in my judgment mean more for the peace of the world and the people of the various countries than almost anything else we can do, and they do more to break down sectionalism, to bring about better understanding of the problems of the whole country, to bring about a national feeling in the United States, in maintaining patriotism, than anything else that can take place within the confines of the United States.

You may travel on the train but when you travel by train you do not come in contact with the cross-section of the country as you do by automobile. When I want to find out what is going on politically in this state or the nation, I don't go in the Pullman car to find out; I don't go in the hotel lobby to find out what public sentiment is. I will stop at the filling station and ask the boy at the filling station what the public feeling is or at the restaurant or barber shop and I would sooner have the advice and judgment of the boy at the filling station or the men at the restaurant and barber shop than have the opinion in the Pullman car and the hotel lobbies.

At the present time if you should go into the hotel lobbies you would say without a question of a doubt that the next president would be Mr. Landon. If you get out in the sticks among the farmers these people will give you quite a different story, I am sure. The boys in the Pullman cars just talk to themselves and they think that is public sentiment. I take a cross-country trip and I ask these other people what the public sentiment is and what the people are thinking about and I learn much more from these trips by automobile, talking to individuals who work in the shops and factories, on the farm and in the meeting places of the ordinary man. I learn much more of public sentiment than I do from going around these other places.

I must tell you a story about the late Senator Long from Louisiana. Senator Long sat beside me in the Senate. When he was at the height of his popularity, one of the fashionable ladies in Washington asked me if I would not try to get him to come to a dinner which she was giving. Strange as it may seem, many of the society leaders were very anxious to have Senator Long dine with them. When I asked the Senator to come to dinner he said: "No. I never go to dinners. I can't learn anything by going to society dinners. I can't learn and I don't want to go anywhere unless I can learn something from somebody. I can't learn anything coming in contact with most of the people going to these society dinners. Occasionally I can get an idea from you but it is only occasionally, and from most of the people I can't get any ideas at all."

I do want to say this to you. I am not going to keep you long. In the Senate you know, we can talk as long as we want to, but I am not going to abuse the privilege which you have accorded me this afternoon. The building and maintaining of good roads is one of the fine things that we have done in the United States of America which I want to keep up and I want to see good roads built everywhere, except that I don't want to see any more good roads in Glacier Park. I think this park should be maintained as a trail park. So many people come to Glacier, ride through and say, "I have seen Glacier Park." Don't you men make that mistake and say you have seen Glacier Park because you have come up here and even though you go over "Going-to-the-Sun-Highway," because you will have only seen a comparatively small part of Glacier Park. Most of the beauties of Glacier Park are far off of the beaten trail and the way to see and appreciate them is to hike over the mountains, over the trails, or get on a cayuse and go out and stop at the camps, and go wading in the streams and lakes. I know because I have put in twenty summers in Glacier Park on the other side, and I haven't seen Glacier Park yet. I have visited a great many glaciers and most of the lakes but I haven't seen it yet. You can't appreciate the beauties of this park by riding through in an automobile. You can't appreciate the beauties of this country by riding through on a train. To appreciate the beauties of this country, to appreciate the greatness of this country and the greatness of the people of this country you have to go by automobile and go by a still slower method to appreciate the beauties of Glacier National Park; go on horseback or hike, as a great many people do.

I am glad to see so many people coming to Glacier Park. It is still more unfortunate that you will not be here a month and go out and take the old fishing pole and use it in the lakes, get out in a tent or sleep outdoors, some of these places where you can wake up in the morning and hear the stream running down below you and see the bears and the deer and the porcupines, and hear the coyoes howl at night, and go out on one of these little lakes and catch a nice mess of fish. I remember just a few years ago, the last time that my colleague, the late Senator Walsh, visited me up here. We went up to Arrow Lake and slept in one of the cabins. We had a boy with us who did the cooking and we caught a nice mess of fish and cooked them, just fresh out of the water; we had a few potatoes, a little toast, and some coffee and then Senator Walsh and I went out in front of the cabin. The moon was just coming over the top of the mountain and Senator Walsh said to me, "Bert, no king has anything on you and me tonight." How true it is. How many people there are in the United States today who do not appreciate the beauty of this country; how many who do not appreciate the greatness of this country and how many of them here in the United States do not appreciate the privileges which are extended to them. All they have to do today is go to Europe where every mother when she gives birth to a child is wondering how soon or how long before that child is going to be put in the army to be made into cannon fodder. Go any place in the world and then you appreciate more the privileges which we are blessed with in this country. Sometimes I wonder as I go about, whether we are going to be able to keep from going through the same things in the United States as they are having in these other countries. We can stop it. We can prevent it, but the question is whether we have sense enough to do it. That is the question that governs the American people at this time; can we prevent and keep from going through the same thing that is going on in various countries in Europe? That is the real issue that confronts the American people. I sometimes doubt whether we have the power to do this because we have shown so little judgment in many respects, but in one respect we have shown a great deal of judgment and that is that we, the founders of this country, made this the United States of America and this vast free-trade area with no barriers of any kind where people have free speech and free press, where we can have liberty as it is known only in the United States of America today and where we have the roads and means of communication to help us maintain and preserve our liberty as it is not being preserved in other parts of the world.

I thank you all for your extremely kind attention and hope that I have not bored you too much by trying to tell you about other things than good roads. You can appreciate now what Dr. McGregor told me about not knowing very much about good roads. I thank you.

SECTION II.

PAPERS PREPARED ON, DEVELOPMENTS AND FUNDAMENTALS OF SUCCESSFUL BITUMINOUS PRACTICE and the ANALYSIS AND REVIEW OF THESE PAPERS AS PRESENTED AT THE CONFERENCE BY THE CHAIRMAN OF THIS SECTION.

QUANTITY OF LIQUID ASPHALTIC MATERIAL IN DENSE GRADED MIXTURES

By C. F. Ramey, Assistant Chief Chemist,
Standard Oil Company of California.

The determination of the quantity of liquid asphaltic material to use with a given aggregate is of such great importance, and the ideas and opinions with respect to this subject are so varied, that a paper such as this can present only the procedure followed by the various state highway departments participating in this Bituminous Conference. In view of this, the viewpoints and experiences of those state highway department representatives who have replied to my inquiry on the subject "Quantity of Liquid Asphaltic Material To Be Used in Dense Graded Aggregate" will be discussed. Formulas for the determination of liquid asphaltic material content have been developed and are now being used by many of the highway departments of the western states. In certain instances the application of any one formula serves only as a guide in establishing the proper proportions, the experience of construction engineers and information derived from actual laboratory mixes being considered extremely important for satisfactory results.

Many short-type formulas have been purposely developed by some of the states without consideration being given to all the factors such as absorption, viscosity, film thickness, specific gravity, temperature of application, etc. This type is apparently sufficient for the average condition encountered in the state, with which its author is familiar. In general, the short type formulas are based on the percentage of material retained on the 10 mesh, the percentage between the 10 mesh and the 200 mesh, and the percentage passing the 200 mesh, each percentage being multiplied by a predetermined constant. It is the opinion of others that the correct method of determining the percentage of liquid asphaltic material to be incorporated in a mixture depends on the surface characteristics of aggregate, absorption factor, specific gravity factor, film thickness, etc. As a result of this opinion, there are, then, the more elaborate formulas based on recognition of these factors.

Formulas representative of the short type are: The McKesson-Frickstad, New Mexico and Wyoming. More elaborate formulas, based on a complete sieve analysis as well as the surface characteristics of the aggregate, are: Missouri, Wisconsin, Michigan, and the California Surface Area Method of F. N. Hveem.

In the progress report on light asphaltic road oils prepared by C. L. McKesson and W. N. Frickstad in 1927 there is shown an empirical formula which had been developed and was tentatively submitted as of value in estimating the quantity of liquid asphaltic material required in surface mixtures, as follows:

$$P = .015a + .03b + 0.17c$$

Where P = percent of oil by weight,
a = percent of material retained on 10 mesh,
b = percent of material passing 10 and retained on 200 mesh,
c = percent of material passing 200 mesh.

Experience indicated the necessity of modifying the McKesson Frickstad formula since the numerical coefficients gave too low a liquid asphaltic material content as well as variable results over a wide range in grading and type of aggregate. Many formulas have been developed and modeled more or less along the lines of this formula, however.

The practice in the State of Montana for plant mix is the use of the McKesson-Frickstad formula plus 25% additional asphaltic material; thus—

$$P=1.25\,(.015a+.03b+.17c)$$

It is felt that this formula serves the purpose for the mixes designed and that utlimate satisfaction depends on local conditions and, further, the results by use of this formula can be modified as required to procure a properly treated aggregate.

In the event filler is added to the aggregate, this is blended at a trap where, knowing the grading of the material on the conveying belt, the operator can accurately apportion sufficient filler to guarantee a well graded product in the bins. In the case of road mix, the screen tests of the material in the stacks and the volume thereof will govern in determining the liquid asphaltic material content. It has, however, been definitely established in road mixes that the maximum liquid asphaltic material content shall not exceed 4 percent. A table has been established showing the percent aggregate passing a ¼-inch screen and the thickness of the compacting mat, by means of which the asphaltic material required in gallons per square yard can be determined.

During the season of 1935 both MC and SC asphaltic materials were used, and Montana has tentatively adopted the use of the MC type for materials tending to have high absorption values and restricted the use of the SC type to materials having low absorption values.

The practice in the State of Wyoming originally was the use of the McKesson-Frickstad formula, but after some experience it developed that it was necessary to add approximately 30% more liquid asphaltic material than the formula indicated. At the present time Wyoming is using no established formula, and recommendations are based on actual mixes of the materials used. Samples as received from the field are mixed in the laboratory with the liquid asphaltic material to be used on the project until the mix presents the proper appearance. The mixed material is then compressed in a 4-inch cylinder to 3000 pounds per square inch, and from the weight of material used and the resulting volume obtained the weight per cubic foot in the oil-compacted state is thus obtained, and used for the purpose of estimating quantities of both liquid asphaltic material and aggregate. It is felt that this is not a hit-or-miss method of arriving at the proper quantity, due to the fact that field men have had a great deal of experience and are able to detect very quickly any errors due to possible change in grade of material in the field.

The practice in the State of Iowa is the use of the so-called Wyoming formula which is a modification of the McKesson-Frickstad formula, and they find for the SC type of material this formula affords the correct quantity of material. In the case of RC and MC types it has been found necessary to increase the quantity of asphaltic material by approximately the amount of volatile material present. Due to the large amount of rainfall and the varying weather conditions during the construction season, Iowa has found the inverted penetration method of construction more satisfactory than the road mix method.

The practice in the State of New Mexico is to use a formula which expresses values in slightly different terms, as follows:

$$P=0.02(a)+0.07(b)+0.15(c)+0.20(d).$$

Where P=percent liquid asphaltic material required.
a= " aggregate between 50 mesh sieve and maximum size.
b= " " " 50 " " and 100 mesh sieve.
c= " " " 100 " " and 200 mesh sieve.
d= " " passing 200 " "

All percentages shown in this formula are by weight, on the basis of total untreated dry aggregate, and this formula is applied for SC type materials, while for cutback asphalts the recommendation is for an increase in the quantity of liquid asphaltic material 1¼ to 1½ times that indicated by the formula. This formula was developed by taking the separate sizes below the 50 mesh and adding liquid asphaltic material in increments for the production of specimens under definite control conditions, the specimen being selected that gave the greatest resistance to impact and the percent of liquid asphaltic material established on this basis. Sizes above the 50 mesh were merely coated and the coating determined, the whole being checked with specimens made from mixtures wherein the liquid asphaltic material content was varied. Assuming the size below 50 mesh contained the correct percentage, the remainder was then assumed to be the approximate optimum for the larger sizes of particles.

The factors of absorption, film thickness, specific gravity, were purposely not included in this formula, and it is the opinion of the authors of this formula that it is satisfactory for all practical purposes for material within acceptable limits and affords a very simple formula that can readily be used within the limits of refinement obtainable in the field; further, that it permits the field men to continue their work without having to consult tables or depend on the laboratories.

The general practice in the State of Kansas in its bituminous dense graded aggregate type mat construction is use of the New Mexico formula. This method has been found adaptable to MC types of asphaltic materials except in cases of extreme density of the total aggregate. Provided the total aggregate weighs 128 to 131 lbs. per cubic foot, the New Mexico formula will indicate an excess of asphaltic material and corrections are made for this condition. The SC types of material have not been used in Kansas since road oils have been so designated, but prior to this designation it was found that the New Mexico formula was quite adaptable to road oils for aggregates containing not more than 15% passing the 200 mesh sieve.

The practice of the State of North Dakota is to establish the quantity of bituminous material required in the mix as nearly as practicable, in accordance with the following formula:

$$P = .105A + .063B + .84 + V$$

Where P = Per cent of liquid asphaltic material
A = The total amount by weight of dry aggregate passing 200 mesh sieve
B = The total amount by weight of dry aggregate passing 10 mesh sieve
V = Void correction

While the factor V appears in the above formula, it may be disregarded except where the void content in the aggregate is exceptionally high. The percentage of voids in the dry aggregate is then computed from the first part of the formula and the weight converted to percentage by volume. This is then subtracted from the percentage of voids in the dry aggregate. If the remaining voids exceed twelve (12) percent, a volume of bituminous material is added sufficient to fill the voids in excess of the twelve (12) percent. By then reducing this volume to terms of weight the percentage of additional material to be added to that already determined by the formula is found.

It has been found that this formula gives very satisfactory results when using the softer aggregate obtainable in the southern part of the state but that it will carry too much asphaltic material when applied to the use of the harder aggregates encountered in the northern portion of the state. The asphaltic material used in dense graded mixtures has been MC-2 and MC-3 grades and the very heavy SC types.

The practice in the State of Utah is to maintain a very accurate control of the quantity of liquid asphaltic material to be added to the gravel, and laboratory and field tests permit them to predetermine the best mix for obtaining correct results. A rather elaborate formula for the calculation has been offered, but a simpler formula is in use in Utah which will serve for average conditions, as follows:

$$P \equiv .01A + 0.043B + .195C + H$$

Where P=Percentage of liquid asphaltic material
A= " aggregate larger than No. 10 mesh
B= " " smaller than No. 10 mesh and larger than No. 200 mesh
C= " " smaller than No. 200 mesh
H=Field absorption factor

The field absorption factor is obtained by means of an absorption test. An arbitrary assumption is made and it has been closely enough borne out in experience that the completely dried material will absorb within its pores in five hours as much water as it will oil under road conditions.

The test run in connection with the wash sieve test in which the following sieves are used: 1 inch round, ¾, ½, ¼, Nos. 10, 20, 40, 80, 100 and 200 mesh square. The part of the sand passing the No. 200 mesh sieve is rejected for this test. It is always sticky and interferes with the surface drying operations. The sizes retained on the above sieves are immersed separately in water for five hours and then surface dried. The gain in weight represents the absorption of the material. In practice on the road we determine the lowest point to which the moisture content of the material can be reduced with reasonable work on the part of the contractor. This moisture content is subtracted from the laboratory absorption factor furnished the engineer to obtain the field absorption factor. The laboratory work connected with this test is very exacting. Skill and judgment on the part of the operator is required to find the exact end point in the drying operation.

The method followed in Oregon, insofar as plant mix is concerned, is that proper proportioning of aggregate is obtained with not less than four bins of aggregate, the proportioning of aggregate and asphaltic materials being controlled by weight. The determination of the correct quantity of asphaltic material is dependent on the sieve analysis of the aggregate as in any asphaltic concrete mixture. It is the opinion that formulas are of little value and that success in the mix is dependent more or less upon the workmanship and judgment of those in charge of such mixtures, particularly with road mixing which has the inherent defect of lack of control of graduation of the aggregate and the percent of the asphaltic material.

The practice in the State of Washington does not include the use of any formula for determination of liquid asphaltic material content, and at the present time road and plant mix surfaces constructed in this state have been limited to a few relatively small projects, most of the bituminous construction being of the penetration macadam type. The practice is to depend on the judgment of the field engineer to determine the best percentage of asphaltic material under the conditions obtaining on such a project. Except for a few instances early in the history of mix treatments, the results have been very satisfactory and have been influenced, no doubt, by the supply of first class aggregate obtainable in Washington and the fact that it has not been necessary to use materials unusual in characterictics or grading. It is felt that the employment of experienced inspectors, as well as constant inspection of each day's work and proper understanding of conditions to be met, will in the end result in the best type of construction. Formulas have been of little assistance in the first calculation of quantities of asphaltic material, but in nearly all instances it has been found that the field engineer can best determine these quantities since it is necessary to make variations, taking into account the following factors which are not susceptible of evaluation by means of formulas:

(a) Location of the roadway to be treated with respect to climatic and traffic conditions to be expected.

(b) The grade and type of liquid asphalt cement specified for use.

(c) The grading, surface characteristics and texture of the mineral aggregate.

(d) Whether or not the newly constructed roadway will be sealed within the current season or left unsealed until a later date.

Grades of liquid asphaltic material used in dense graded mixtures in current construction in Washington are SC-2 and MC-2 for the road-mix type, Class B, and RC-3 and RC-4 for the plant-mix type, Class F.

The practice in the Province of Saskatchewan in plant mix work is the use of 3½ to 4 pounds of liquid asphaltic material to 100 pounds of aggregate, the aggregate being generally igneous of glacial origin and of quite constant specific gravity. The asphaltic material used is of the heavy SC type of approximately 85 softening point, and this has been found satisfactory only for roller finishing, except in hot weather when it can also be bladed for a part of the day. For road mix work, MC-3 type material is used, the actual quantity incorporated in road mixes being left to the judgment of the resident engineer in charge of the project, but in either the road mix or the plant mix work lean mixtures are favored. Although familiar with the various methods for determining quantities of liquid asphaltic material, it is their feeling that the various formulas are no more accurate for the purpose of setting a mix than their actual experience.

The practice in the State of Nebraska is use of modified New Mexico formula. The most significant change in the formula is the introduction of the factor "S." Following is the formula:

$$P=AG(.02a)+.06b+0.1c+Sd$$

Where P—Per cent bitumen by weight at the time the bituminous mixture is laid;

A—Absorption factor for aggregate (for hard gravel, granite, or other similar materials this factor is equal to unity);

G—Gravity Correction Factor (computed by dividing the bulk specific gravity of the aggregate to be used into 2.62 which is the bulk specific gravity of Platte River gravel);

a—Per cent of the aggregate retained on the No. 50 sieve;

b—Per cent of the aggregate passing the No. 50 sieve and retained on the No. 100 sieve;

c—Per cent passing the No. 100 sieve and retained on the No. 200 sieve;

d—Per cent of aggregate passing the No. 200 sieve;

S—A factor, the value of which depends upon the character and absorptiveness of the portion of the aggregate passing the No. 200 sieve.

The methods used in the practice followed by the State of California include both surface area determinations, based on a complete sieve analysis, and consideration of the surface characteristics of the aggregate. This is founded on the method of

"Surface Area Analysis" largely developed by F. N. Hveem of the California State Highway Department. The method outlined makes necessary the use of a table of surface area constants, a chart for determining liquid asphaltic material content from surface area of combined aggregate, and a table showing differences in surface area coefficients calculated from a small number of screen sizes as compared to values obtained by using a full set. These tables and chart are shown in a paper by Thos. E. Stanton, Jr., and F. N. Hveem on "Role of the Laboratory in the Preliminary Investigation and Control of Materials for Low Cost Bituminous Pavements"; Part 2 of the Proceedings of the Fourteenth Annual Meeting of Highway Research Board, December, 1934. This method, as outlined by Mr. Hveem, is, in general, based on analyzing the material by sieving and determining surface area values from sieving analysis with recognition of the following factors:

First: The optimum liquid asphaltic material content is directly related to the surface capacity of the aggregate. This surface capacity is affected by three factors, each of which may vary independently of the others:

(a) Most important is variation in surface area due to variation in grading. For the same weight, small particles have a greater surface area than large ones.

(b) Variation in surface area due to shape and character of surface of particles.

(c) Variation in absorption capacity of different aggregates.

Second: It has been established that the thickness of oil film or coverage factor must be varied according to the **average** size of the particles.

A constant is assigned for each size which represents the surface area in square feet per pound for the size groups. The percentage factor of each size is multiplied by the appropriate constant for that size. The results added give a surface area equivalent for the grading represented by the entire sample. This method may be used in connection with any number of sieves. More accurate results are obtained with a large number of size divisions, particularly of the finer particles.

The results thus obtained represent a mathematical relationship between surface areas of different aggregate gradings. Variation in surface area between different classes of materials of the same grading, due to difference in shape and surface characteristics of the particles, must be estimated by inspection or determined by proper laboratory tests. Rough, irregular particles have, of course, a greater surface area than smooth, spherical ones. Variation in absorption must be determined by trial or laboratory tests. This variation is due to the capacity of different rock structures to attract and hold varying thicknesses of asphaltic residue on their surfaces. At the present time the formula is applied in a table which has been compiled to permit use of either a full set of testing sieves or a smaller number, the table to be used depending on the number of sieves available. The dust content should be determined by washing through a No. 200 sieve or by elutriation.

Having arrived at the surface area equivalent for the grading represented, the amount of oil required is calculated by multiplying the surface area by the "bitumen index." The "bitumen index" is a variable factor indicating the amount of oil in pounds required to cover one square foot of surface area. It has been established that the oil film or coverage factor must vary according to the average size of the particles. The "bitumen index" chart gives the coverage factor range that may be applied to different surface area equivalents. It will be noted that in fine grading combinations which have high surface area equivalents the coverage factor is smaller and the tolerance more restricted than in coarse combinations.

Corrections must be made for aggregate having a specific gravity above or below 2.65; a lighter aggregate will require more oil by weight and a heavier rock will require less. In order to definitely determine and measure all the factors which may be present and correctly evaluate their effect on oil content and quality of mix, it is necessary to make a laboratory study of the material and furnish the field men with constants that are correct for the particular aggregate being used. Considerable difference in quality of results may be anticipated with different aggregates, regardless of structural strength, resistance to abrasion, or grading.

Considerable effort is made to determine the precise surface factor which will provide the optimum liquid asphaltic material content for a given aggregate, and when once established the particluar surface factor becomes the only constant. The surface factor, or "oil line," furnishes a practical means of comparing the relative degree of oiling between a fine mixture requiring a high oil content and a coarse grading requiring much less.

An attempt is made to select curves which will give an oil content both above and below the assumed optimum. Test specimens are formed from these mixtures and tested for stability in the Stabilometer. This test, being primarily a measure of internal friction of the mass, indicates the presence of excess oil by measuring the reduction in friction. From these test results, and consideration of local conditions, the surface factor or oil line is established and used as a basis for recommendation to the construction forces.

In fixing the amount of oil for a given aggregate and grading, it is with the general assumption that the most desirable oil content is the largest amount the aggregate will tolerate without developing instability. It is believed that all other considerations, such as resistance to moisture, raveling, impact, and oxidation are best met with a relatively high oil content. In the event of reworking, richer mixtures are preferable.

Having fixed the proper surface factor (oil line) and having computed the surface area equivalent from the grading of the aggregate in use, the following formula is used:

$$R = \frac{2.65}{Ga} \times \frac{Gb}{.98} \times SaBl$$

Where R=Liquid asphaltic material or bitumen ratio.
Ga=Specific gravity of combined aggregate

$$Gb = \text{Specific gravity of bitumen} = \frac{141.5}{131.5 + \text{A. P. I. Gravity}}$$

Sa=Surface area equivalent of aggregate in square ft. per lb.
Bl=Bitumen index as determined from chart. Surface factor from laboratory recommendation.

For this type of mix the SC and MC asphaltic materials are used.

The practice in the State of Michigan for the construction of liquid asphaltic material aggregate surface course is the use of a formula for the determination of the quantity of oil which has been adapted from the work done in California, based on surface area analysis. The materials are combined to produce a mixture containing asphaltic material in amount as determined from the following formula and with materials passing a 200 mesh sieve from 5% to 10% by weight:

$$r = k + .041\ y$$

Where: r=lbs. of oil per 100 lbs. of aggregate with sp. gr. of 2.65
k=constant depending upon shape and absorption of aggregate
y=surface area variable depending on grading of aggregate.

The constant (k) is determined for various aggregates by laboratory tests (k=2.71 for average Michigan aggregates). For average Michigan aggregate:

$$r = 2.71 + .041\ y$$

The surface area of any grading is determined as follows:

Percent retained on No. 10 × 4.. =
Percent passing No. 10 retained on No. 40 × 18...... =
Percent passing No. 40 retained on No. 200 × 80.... =
* Percent passing No. 200 × 250...................................... =
Surface area (y).. total.

*The surface area factor for material passing the 200 mesh sieve is somewhat of a variable depending upon absorption, however, for average silts and commercial fillers a factor of 250 is satisfactory while other fillers such as marls, some silts and sugar beet lime may require a factor as high as 1000. Each filler is tested and proper factor selected to correct for absorption characteristics.

The oil ratio (r) is corrected for sp. gr. of aggregate as follows:

$$R = \frac{2.65\ r}{\text{Specific gravity of aggregate}}$$

Where: R=lbs. of oil per 100 lbs. of aggregates used

The per cent of oil is determined from formula.

$$\text{Per cent of bitumen} = \frac{100\ R}{100 + R}$$

After establishing the oil ratio according to this formula, which is lbs. of liquid asphaltic material per 100 lbs. of aggregate with a specific gravity of 2.65, this ratio is corrected for the actual specific gravity of the aggregate. The construction methods are by the use of traveling plant road mix or stationary plant mix, and the types of material used are designated as SC-3A and SC-4A, these materials being practically identical with the SC-3 and SC-4 materials of the Bureau of Public Roads.

The practice in the State of Wisconsin is the use of formulas originally developed for use with SC materials, and by the introduction of some modifications in the factors they are applicable to cutback asphalts as well. These formulas are based on the conditions inherent to road mixing where the mixes should contain sufficient bitumen to thoroughly cover the surface of the aggregate. With this thought in mind the various factors were developed and each factor studied individually and based on definite measurements. The formulas in use are based on absorption factors, specific gravity factors and film coefficient factors and have been used in the field under various conditions of application. As a result, the following conclusions have been reached:

1. The formula is workable and produces a good mix with all particles coated, provided the proper absorption factor is used.
2. The percentage of bitumen as calculated by the formula checks well with the percentage determined by experienced men.
3. The per cent of bitumen calculated by means of the formula can be applied readily with the type of equipment in use in Wisconsin.
4. The formula has been found to be an excellent guide to determine the per cent of bitumen to be used, but it cannot be used blindly. Due to nonuniformity of the quantities of the aggregate and its gradation, especially at sags in the grade line, "spotting" is often necessary.
5. When aggregate batches are mixed with the calculated percentage of bitumen in a small metal pan, the percentage of bitumen applied on the road is held under close control because the inspector is familiar with the correct appearance of the mix.

Two types of slow curing oil—one with a somewhat high proportion of volatile and which is suitable for road mixes containing appreciable amounts of aggregate passing 80 mesh, and the other having a low proportion of volatile and used on road mixes containing a predominance of material passing No. 4 sieve—are being used. The Wisconsin formulas for computing percentages of bitumen for road mixes are as follows:

I—Formula for Mixes Containing a Predominance of Material Retained on No. 4 Sieve:

$\%$ Bitumen by weight $= A \times S \times F\,(.05R_{3/4} + .12R_4 + .04P_4)$

II—Formula for Mixes Containing a Predominance of Material Passing No. 4 Sieve:

$\%$ Bitumen by weight $= A \times S \times F\,(.07R_{30} + 0.1R_{100} + 0.45P_{100})$

A = Absorption factor
S = Specific gravity factor
F = Film coefficient factor
$R_{3/4}$ = Percentage of aggregate passing 2″ or 1-½″ sieves and retained on the ¾″ sieve.
R_4 = Percentage of aggregate passing the ¾″ sieve and retained on the No. 4 sieve.
P_4 — Percentage of aggregate passing the No. 4 sieve.
R_{30} = Percentage of aggregate passing 1-½″ sieve and retained on the No. 30 sieve.
R_{100} = Percentage of aggregate passing No. 30 sieve and retained on the No. 100 sieve.
P_{100} = Percentage of aggregate passing No. 100 sieve.

The practice followed in the State of Missouri is the use of a formula similar to that developed by F. H. Hveem; modified, however, to meet conditions as found in this state. The Missouri formula is as follows:

$$\% \text{ Bitumen (by weight of aggregate)} = \frac{\frac{A-H}{2} \quad \frac{2.65}{Ga} \times BI}{1-V}$$

A = The percent absorption of the aggregate, as reported by the laboratory.

H = The percentage of water in the aggregate at the time the bitumus binder is to be applied; this will have to be determined in the field.

G = The sp. gr. of the combined aggregate as reported by the laboratory.

V = Proportion of volatile matter in the binder which, in the case of type MC oil, is to be taken as ½ the proportion that distills over at 600° F. and, in the case of type SC oil, as ½ the percent loss on heating at 325° F.

BI = The bitumen index and is determined from the attached chart after determining the surface area of the aggregate. The curve number to be used for any given aggregate will be designated by the laboratory after tests have been made on samples of this aggregate submitted from the field.

In the use of this formula the surface area of the aggregate is determined by making a sieve analysis of the aggregate with 1-inch round sieve, No. 10, No. 20, No. 50, and No. 200 sieves. The percentage of aggregate between the sieves is determined and multiplied by a constant, as follows:

	Constant
Per cent retained on No. 10 sieve	4
" passing No. 10 and retained on No. 20	11
" " No. 20 and retained on No. 50	27
" " No. 50 and retained on No. 200	100
" " No. 200	250

Add the products and divide the sum by 100; the resulting figure will be the surface area factor.

Knowing the surface area, the bitumen index is determined from a chart, the formula and the oil lines on the chart being empirical and having been developed from observation of numerous projects constructed over a period of time. Having determined the quantity of bitumen to be used with the aggregate, a mixture is made and subjected to tests in a roller compaction machine which is similar to that used by the Bureau of Public Roads for compacting bituminous mixtures, and by this means the density which the mixture will attain on the road is determined. A satisfactory oil line having been found, as indicated by the compaction test, Stabilometer specimens are made which contain all the bituminous material indicated by the formula, these specimens being subjected to tests for stability. It seems apparent that the surface area method of proportioning, when used in conjunction with the compaction and Stabilometer test, is satisfactory for small variations in aggregate grading.

The material used in Missouri for all bituminous mat construction has been either the SC or the MC type of liquid asphaltic material.

It is quite apparent a marked difference in opinion exists in regard to the type of formula best suited to conditions in the various states. Certain "aids" or additions to the simple formulary results seem necessary in practically all cases—some states make the necesary modifications by "experience," others by "stability" tests, or the like.

It appears necessary to modify any developed formula to meet conditions in the various states. However, the general recognition of the effect of grading or variations in fineness of aggregate, as well as the need for making allowance for absorption or porosity in all cases, indicates that a single formula wherein these factors are included should be satisfactory for an extremely wide range of conditions and aggregates.

Acknowledgment is made to various State Highway Departments for their valued assistance in the preparation of this paper.

MIXING OF AGGREGATES AND BITUMENS

**By Levi Muir, Materials Engineer,
Utah State Road Commission**

Mixing of aggregate and bitumen in the form of road mix came into general use in the western part of the United States in 1927. Early field control methods were simple. A given amount of fuel oil having a 60-65 per cent of asphalt residue of 80 penetration at 77 deg. F. was applied to the aggregate by means of a power distributor and the resulting mass mixed to a uniform color and stain. One and one-half gallons of oil per square yard was the amount used on these early projects. The mat obtained frequently varied in thickness between one and one-half inches and two and one-half inches.

The mixture was checked by means of a stain test before laying, that part of the mixture smaller than 10 mesh being used. The resulting stain gave a rough idea of the amount of free bitumen present on the surface of the aggregate. Satisfactory mixtures made from materials of widely different grading gave stains of different intensity. The amount of filler in the aggregate varied the stains greatly. The test as originally conducted did not prove wholly satisfactory.

Field engineers began to examine the aggregates as to grading and quantity before mixing operations began. This procedure gave the engineer some advance idea of the quantity and quality of the resulting mixture. Various formulae for controlling the mixtures followed, among them being the McKesson-Frickstad, California, New Mexico and Utah. The surface area and void methods of design were used, following the first more or less primitive experiments in control. These systems when used in connection with laboratory experiments, have given good results. The laboratory, by experiment, determines the proper amount of bitumen to use for each aggregate proposed. The surface characteristics of shape and absorption influence the amount of binder required. Laboratory trial mixtures are observed for a time under temperature before stability tests are run. It is often necessary to make three or more trial mixtures before the most suitable oil content for each material is determined.

Theoretical Principles Involved in Mixing and Results Accomplished

Most state highway departments have had experiences mixing liquid asphalt products with great varieties of aggregates of different qualities and gradings. Granting the materials have satisfactory reaction with the bitumen, wide variations of gradings have been found to give satisfactory results when subjected to the destructive forces of traffic. For each grading of aggregate there is a proper quantity of bitumen to give best results. Most investigators agree that the optimum amount of bitumen is the largest percentage the material will carry and still retain sufficient stability under traffic. Such a mixture performs well when subjected to moisture and low temperatures. It is the problem of the laboratory through preliminary investigations and tests to find this optimum amount of bitumen for each material to be used.

The function of the bitumen is to coat each particle of aggregate, large or small, with a film of oil of such thickness that the resulting mixture when subjected to the action of traffic and varying changes of temperature and moisture will remain stable at all times and will resist the abrasion of wheel loads. In bituminous wearing courses stability or resistance to lateral displacement is an essential characteristic. Adequate strength and durability of mineral aggregate and durability of the bituminous binders are necessary.

Many materials encountered show a preference for water instead of bitumen. Such materials usually have high water absorptions and during mixing either at a plant or on the road are almost impossible to dry. Other sedimentary materials having high water absorptions but showing a preference for oil can be dried out during the mixing operations without any serious difficulties. In materials showing a preference for water, the surfaces of the larger particles are especially slow to paint or coat during mixing. In mixing materials on the road, it is essential that the bitumen be thoroughly distributed among the fines and that no clods of free oil be present. It is not serious if some larger sized material fails to coat. When placed and rolled and finally compacted by traffic and heat they become thoroughly coated.

One of the most difficult parts of mixing is to conduct the operation that the proper percentage of bitumen is present at all times. Where the mixing is done at a plant the materials can be handled in such a way as to insure uniformity of grading. Separation of the aggregates into two sizes by accurate screening helps greatly in securing accurate proportions. Having been given the best mixture for the aggregate and a given bitumen, the contractor's job is to duplicate the mixture at the plant.

I have been requested to touch on the subject of uniform film thickness as a method of controlling the mixture. In October, 1935, H. G. Bennett and R. W. Gillies reported the results of a series of stain tests for this purpose. While these tests, conducted at the California Highway Commission Laboratory, were run on sheet asphalt and the minus ten mesh matrix of bituminous concrete mixtures, experiments show the method to be applicable to liquid asphalt mixtures. The method briefly described is as follows:

A cylinder of the mixture is formed at a temperature of 300 deg. F. and six thousand pounds per square inch pressure in a two-inch diameter mould. The mould is recessed at the bottom to a slightly larger diameter to permit the placing of twenty thicknesses of filter paper. When the pressure is applied to the mixture, free bitumen on the surface of the aggregate particles is forced out through the filter papers. For rich mixtures, binder may be forced through the entire number. Drier mixtures may show only two or three papers stained. After compressing the material, the cylinder is forced from the mould and later tested in the Hubbard-Field machine at a temperature of 140 deg. F.

The apparatus used to form the test cylinder in the field is simple. It consists of a Black Hawk recording jack of 20,000 capacity installed in a suitable frame. The heated mixture is taken from the plant and immediately compressed and the stain number noted. Having laboratory curves showing relations between stain, per cent asphalt, stability and specific gravity of the mixtures, the field engineer can readily determine if the mixture is too rich or too lean and he can make predictions as to the probable stability developed by the mixture.

A series of tests were run in the laboratory to show the relations of stain, bitumen ratio, stability and specific gravity. Six different sands were selected for the experiments and were graded as follows:

Sieve Size	Sand Sample					
	1	2	3	4	5	6
Passing No. 10, retained No. 20	28.4	26.8	25.0	23.8	22.2	20.6
" " 20, " " 40	39.9	37.6	35.2	33.4	31.2	29.0
" " 40, " " 80	14.0	13.3	12.4	11.8	11.0	10.2
" " 80, " " 100	2.0	1.9	1.8	1.7	1.6	1.5
" " 100, " " 200	5.7	5.4	5.1	4.8	4.5	4.2
" " 200,	10.0	15.0	20.5	24.5	29.5	34.5

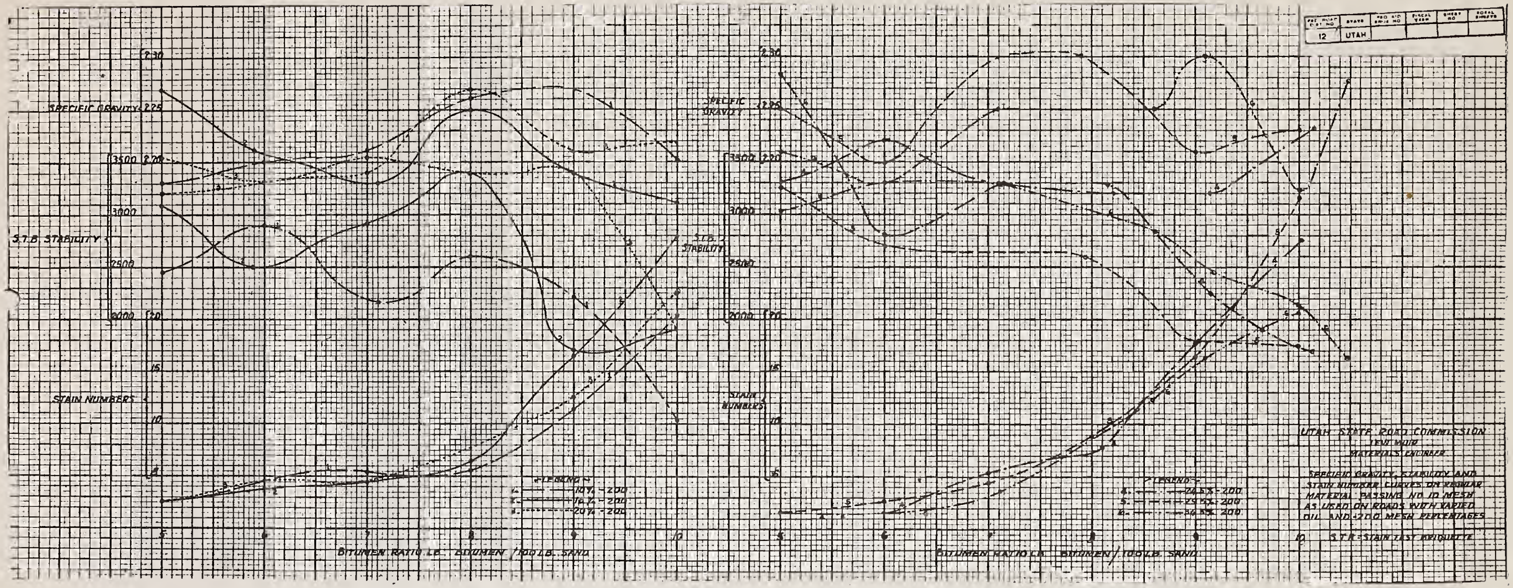
SC-3 was used as the binder in the test mixtures. Six mixtures were made of each sand, using bitumen ratios of 5.0, 6.0, 7.0, 8.0, 9.0 and 10.0. The results of tests are shown graphically on the attached cross section sheet.

Sand No. 1 is comparatively coarse grained. Curve No. 1 shows relation between stain number and bitumen ratios. The curve breaks upward rather abruptly at a bitumen ratio of 8.0. The corresponding curve showing the relation between stability and bitumen ratio is near its highest at this point. The highest stability is found with a bitumen ratio of 6.0, but it is unlikely that such a dry mixture would have sufficient density to withstand the action of water and frost. The highest specific gravity for this mixture occurs at an oil ratio of 9.0.

Sand No. 2 shows maximum stability at a bitumen ratio of 8.0 at which point the stain curve breaks sharply upward. The specific gravity decreased rapidly for bitumen ratios in excess of 8.0.

Sand No. 3 showed comparatively high stabilities with oil ratios as high as 9.0, after which they fell off rapidly. The stain curve breaks most abruptly at an oil ratio of 7.0 and the stability was highest at this point. The highest specific gravity is found at a bitumen ratio of 8.0.

Sand No. 4 had its abrupt change in the stain curve at a bitumen ratio of 8.0 except for the very dry mixtures, maximum stability is found with oil ratio of 7.0 and 8.0.



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LEW MUIR
MATERIALS ENGINEER

SPECIFIC GRAVITY, STABILITY AND STAIN NUMBER CURVES ON REGULAR MATERIAL PASSING NO 10 MESH AS USED ON ROADS WITH VARIED OIL AND -200 MESH PERCENTAGES

S.T.B. = STAIN TEST BRIQUETTE

Sands No. 5 and No. 6 showed less abrupt changes in the stain, bitumen ratio curves. These sands carry higher percentages of fines. Except for the very dry mixture, sand No. 5 shows maximum stability with bitumen ratios of 6.0 to 8.0. Maximum specific gravity is found with bitumen ratios of 7.0 and 8.0. Sand No. 6 shows breaks in stain curve at a bitumen ration of 7.0 and the highest stability is found at this point.

These studies show a very gradual increase in stain numbers for increase in bitumen ratio to a certain point where the curve takes a sharp turn upward. After this point is reached any additional binder adds greatly to the number of filter papers stained. Maximum stability usually occurs at the break in the curve. The specific gravities appeared rather erratic. A pycnometer method was used for this test. The time required to fill the pycnometer may have caused error due to absorption of water by the sample. Some overflow method will be used for future tests.

Previous to this study, we were not able to obtain any satisfactory results when testing liquid asphaltic mixtures with the Hubbard and Fields machine. The extra pressure used in forming the specimen together with storage in air at 140 deg. F. before testing, produces specimens suitable for testing in this machine. The results obtained from the small number of tests so far conducted show a range in values between 400 and 5600 pounds.

The influence of moisture and absorption must be considered in making this test. The grading of the mixtures also has a great bearing on the stain results. The laboratory research work must be conducted under the same conditions, as to heat and moisture, as found at the plant.

In practice the field engineer will be furnished the necessary apparatus to make the stain determinations. Stains will be compared with the curves furnished him by the central laboratory and he will estimate the stabilities. He in turn will submit the test cylinders to the laboratory for final check on stability.

The method seems very suited for Plant mix work. It is less suited for Road mix projects on account of variation in moisture content, material grading and bitumen content. For Plant mix, the method furnishes a means of designing mixes of safe stability.

Before such a method is inaugurated by any highway department, checks should be made on old surfaces to obtain the limits of the Hubbard and Fields values to provide safe stability. A sample was recently taken from a road surface that had been under traffic four years. It was taken from a point where the surface was smooth with no signs of failure. It stained through 3½ papers and gave a stability of 2950 pounds.

In discussing the subject of the mixing of aggregates and bitumen, it is assumed that satisfactory aggregates have been provided for the work and when mixed are to be placed on suitable soils and sub-bases. Also the engineer in charge of the work and the contractor have been provided with proper advance information as to the amount of bitumen required to properly coat the surface of the aggregates to be oiled and that the bitumens used in the mixing are of the liquid asphalt types.

A brief description of the methods of mixing aggregates and bitumen may be in order at this time. Two methods are in general use in the western half of the United States, namely Plant and Road mix. The plants commonly employed are large and capable of producing in excess of 80 tons of mixture per hour. They are equipped with twin pug mixers, large capacity driers and either revolving or vibrator screens that separate the materials into two sizes, the dividing line being at the one-quarter inch size. Proportioning is accurately controlled by weight. Some are equipped with hoppers under the mixer large enough to hold a truck load of mixture. This speeds the capacity somewhat.

Gravel plants of suitable capacity frequently feed the damp aggregates directly to the mixing plant from a belt conveyor. At such a set-up, a small stock pile of gravel is maintained, enough to run the plant a few hours in case of breakdown of the gravel plant. Frequently the gravel is produced in advance and stocked near the plant. The end dump method is usually employed. This system causes much segregation and some difficulty in attaining a uniformly graded product. Better practice provides that the stock pile be formed by the bedding method, or by separating the aggregates into two sizes.

Medium curing cutbacks are almost universally employed as binder for plant mixtures. As the diluents boil at low temperatures, it is not good practice to heat the aggregates above 225 deg. F. Any higher temperature than this will cause very serious loss of binder. The thin films of bitumen are subjected to a very fast evaporation of the diluents when exposed to the action of heat and air in the mixer. Serious changes in the mixture can be caused when the aggregate is heated at too high a temperature. For this reason the aggregates should be thoroughly mixed before the bitumen is added and the wet mixing made as short as possible to paint the aggregate surfaces thoroughly. A total mixing time of 45 seconds is usually sufficient.

Aggregates heated to only 225 deg. F. carry considerable moisture, especially in the rainy fall months. The moisture trouble is always present and it is usually not possible to dry the materials to a point below ¾ of one per cent without danger of changing the bitumen by heat.

Close supervision by the engineer at the plant is very necessary. One man should be assigned to watch the proportioning and mixing. Sieve analysis of the separated aggregates should be run hourly so that any changes in grading can be corrected and proportions changed. If the material in the large bin carries more than 10 per cent undersize, the bin should be emptied and the gravel rescreened.

Road Mix. Two general methods of mixing aggregates and bitumen on the road are employed. Mixing by the use of blades is the one most commonly used. The other system makes use of traveling plants, either self propelled or pulled by large caterpillars.

Different combinations of blade equipment are used. Some contractors prefer motor patrols for this work, while others select combinations of motor patrols, blades powered by large caterpillars and gangs of discs and harrows powered by small caterpillars.

Blade mixing makes use of pressure created by the weight of the material and the heeling operation of the blades in moving the material. In heeling, the mixture is pushed by the rear or heel of the blade. Considerable pressure is created as the mixture is lifted and rolled over the windrow. Temperature also plays an important part in road mixing. On some extremely hot days, these mixtures have been found to be as high as 160 deg. F. temperature. Under such favorable conditions the drying and mixing is very simple. Where moisture and lower temperatures are encountered, the problem is somewhat complicated, very much less speed in mixing being obtained.

A very brief description of road mixing with blades is as follows:

The gravel may be in place in the completed gravel road or it may be stocked in a windrow on a shoulder. If in place, it is scarified to the proper depth and thoroughly dried by the action of discs, harrows and blades. Drying is required if the gravel has been previously stored on the shoulder of the road. Tests for grading of the gravel are conducted at different points to aid in predetermining the required amount of bitumen. The windrow is also checked for size. These measurements assure the proper quantity of mixture carrying the correct amount of binder.

After preliminary measurements and drying have been completed, the gravel is spread over the grade and oil applied. Spreading is very important and should be done with high class power equipment and skilled operators. Bitumen is usually spread in several operations of about one-half gallon per square yard, being followed immediately by a gang of discs and harrows to protect traffic from free bitumen. Oil is usually spread on one-half of the road while traffic uses the other half.

When oil spreading has been completed the mixture is collected in a windrow and mixing by blades commences. The operation consists of blading the material back and forth from one side of the road to the other. Some contractors use motor patrols only, for this work. Others use combinations of large graders pulled by caterpillars and motor patrols. Discs and harrows are used as a valuable aid to mixing in each case. The caterpillars have enough power to move a large portion of the material in one operation. The motor patrols are used mainly to clean the floor before the next movement of the mixture is made by the graders.

One system makes use of discs and harrows to do most of the mixing. The large caterpillar drawn graders turn the mixture, exposing new aggregate to the action of the discs and harrows. It is very necessary that the floor of the road be kept free of partially mixed oiled gravel during each movement of the mixture. It is dangerous to drop off part of the mixture on the floor before mixing has been completed. Spreading of the mixture should be done with motor patrols. No caterpillar drawn equipment should be permitted on this part of the work.

The traveling plants have been used in many states to mix aggregates and bitumen on the road. One type is entirely self propelled and picks the material from the windrow, elevates it and passes it through a pug mixer and deposits the completed mixture in a windrow on the opposite side of the grade. In ordinary summer weather the plant does all the mixing required, it only being necessary to spread the mixture with motor patrols. Predetermination measurements by the engineer are necessary as in the case where mixing is done by blades. The machines are equipped with accurate oil boots and meters, making it possible for the engineer to check the mixture as to bitumen content at any time.

Other traveling plants are pulled by large caterpillars. The machines are drawn through the aggregate. The mixing mechanisms are turned by a power takeoff from the caterpillars. Two types make use of pug mills to do the mixing. These machines are too small to mix the entire amount of aggregate in one operation, making additional predetermination necessary before mixing commences.

Control is very definite and easily accomplished where traveling plants are used. Some states such as Utah, require high class traveling plants for all road mix work on main highways. Short projects on secondary roads permit the use of blades for the mixing.

Advantages and Disadvantages of Central Plant and Road Mixing.

Plant Mix. Uniformity of mixture is one of the important advantages of plant mix over road mix methods. The materials can be prepared and stored at the plant and site and handled during the mixing so that a very high standard of uniformity is attained. Modern plant mix jobs when constructed on proper subgrade soils and sub-bases give uniformally good results from one end to the other. Control of uniformity of surface and thickness is definite at all times. Moisture is more easily reduced in plant mixes than on road mix jobs. In damp cool weather the capacity of the plant is slowed somewhat but operations continue on many days when it would be impossible to dry the aggregate with road operations and as a consequence the length of the season is prolonged where the plant mix type is used.

Plant mix jobs require less bitumen than road mix work, making use of the same aggregate. The difference is usually at least 20% and more in some cases. In cases where aggregates are very high in fines the drier can be made to blow a considerable percentage free of the plant, thus improving its quality and very greatly reducing the amount of binder necessary to paint the surfaces. A certain canyon road was recently oiled by road mix, largely because the road had been built the year before and enough gravel was found in place. The aggregate was very fine grained, containing more than 20% passing the 200 mesh screen. The fines had the proper reactions with oil but were very slow in giving up moisture. A small amount of rain fell each afternoon. The contractor worked for five weeks on a stretch just about six miles in length. The mixing alone cost $2000.00 per mile. Had the material been handled by the plant mix method, the fines would have been reduced to 10 percent or less, making a saving in bitumen of at least 250 barrels per mile. Heavy cutback could have been used as binder. It is safe to say the actual cost to the contractor of oiling this stretch of road by the road mix method was higher than it would have been had the plant mix been employed.

Detour troubles are made simpler where plant mix is used, especially is this true in canyon sections. Many states therefore use plant mix for mountain construction.

In certain localities where the only available gravel deposits carry high percentages of fines, the plant mix method is less costly to construct, and the resulting road is very much superior as to uniformity and cheaper to maintain. Such materials are very sensitive to oil and where the road mix method is used they frequently corrugate under traffic.

It permits use of higher viscosity liquid asphaltic material, thus providing additional stability and durability of surface.

Plant mix is adapted to mass production. Plants are usually worked from 16 to 20 hours per day and the output between 1200 and 2000 tons daily.

Road Mix. Roads built by road mix methods, where the aggregates are favorable in grading and can easily be dried, are less costly to construct. The greater part of the mileage oiled in the mountain states falls in this class.

Under average conditions uniformity closely approaching plant mix can be attained.

The method is very well adapted for use in the arid and desert sections of western United States where very little moisture is encountered.

This plan makes use of machinery usually owned by contractors and highway departments. Expensive, special mixing plants are not necessary.

Under favorable conditions of weather and material, the speed of mixing is comparable to that of plant mix.

Use can be made of the average roadside gravel found and which can be produced at a very low cost.

Where enough suitable gravel is found on an old road a great saving in cost is made over the plant mix method.

Some lack of uniformity as compared with plant mixtures is found with this method, which could be largely eliminated at extra expense by refinements in preparing the gravel, such as separation into two sizes before delivery to the road. Where such methods are necessary it is generally considered better practice to use the plant mix.

Road mix can utilize more than one source of aggregates to a project on account of not using a central plant. This reduces the cost of aggregate.

Road mix surfaces can be readily reworked in case of failure.

Low viscosity oil is necessary in road mix except where traveling plants are used.

The cheaper type of bituminous construction covered by these two types was developed through the necessity for an economical, dustless surface for the large mileage of highways in sparsely settled areas in states which could not afford high type pavements for such roads. The first work done using the road mix type and utilizing, largely, aggregates in place, has served its purpose admirably and has clearly demonstrated the value of such constructon. Many of these old surfaces are on bases which are very thin, affording poor support and were frequently constructed from aggregates not of the best quality for this type of construction. Practically all of them utilized low viscosity oil which is now infrequently used.

The development of the plant mix type has come from experience gained from the old original road mix surfaces.

Description of Some Typical Types of Mixture Used, With the Advantages and Disadvantages

Two general types of mixtures are produced by mixing aggregate and bitumen, namely close graded aggregate and open graded aggregate.

The greater percentage of mileage of bituminous surface found in the western part of the United States is composed of the close graded aggregate type. It makes use of aggregate graded from coarse to fine and is low in voids. The bituminous binder may be either of the SC or MC groups. The maximum size of the gravel is usually one inch, but materials ranging down to sand have frequently been used with success.

Specifications usually require all aggregate to pass a one-inch round opening. The material smaller than ¼-inch varies between 45 and 75 per cent while that passing a 200-mesh sieve should preferably vary between 5 and 10 per cent. For average material the bitumen content will vary between 3½ and 6 percent of the total.

One of the principal advantages of this type of mixture is the fact that the average roadside gravel found can be made satisfactory for use with very little expense in preparation. In most western states the cost of gravel in place in the road varies from 35c to 70c per ton. The great percentage of the run of pit material can be used. The oversize is always crushed but sometimes it is necessary to waste excess fines. The low cost of the material and the fact that gravel of greatly varying quality and grading can be adapted to its use have made this type so successful.

Many different grades of liquid asphalt products have been used successfully. Some stretches of road have been constructed using kerosene cutback with as much as 35% diluent. The resulting mixtures have served under traffic for five years with very little maintainance. Slow curing products with furol viscosities as low as 130 seconds at 122 deg. F. have been used in late fall road mix work. A considerable mileage of these surfaces have performed for more than five years with very little signs of failure. Most specifications now require SC-3 as the binder for road mix and MC-3 or 4 is used where mixing is done at the plants. SC-3 serves very well for the binder where the road mix method is used, except in late fall weather when low temperatures and moisture are encountered. Under such conditions SC-2 greatly reduces mixing costs. Aggregates must be very favorably graded to permit the use of cutbacks for road mix. If the aggregates have coarse grained sands and small percentages of filler, MC cutbacks can be used provided the weather is favorable. With the plant mix method, the hot mixture can be handled on the road before it sets sufficiently to cause trouble in spreading and finishing. The long period of time required for mixing in road mix, causes much of the diluent to be evaporated before the mixing is completed. The resulting mixture is frequently unworkable, thus giving an unsatisfactory surface.

Open Graded Types. Open graded mixed types are sometimes used to resurface old surfaces that have become uneven under traffic. They may vary in thickness from one-half inch to two inches. The aggregate should preferably be all crushed and must be very hard and tough to withstand the weight of the roller without pulverizing. The lack of sufficient material of such quality in many locations has caused highway departments to adopt the close graded type. The open graded type has been used successfully to resurface old partially worn macadams and concrete pavements.

A brief description of the methods of construction of these retreads may be desirable at this time. The old surface usually is given a tact coat of suitable cutback. In the case of concrete it may be either R-1-2-3, rapid curing cutback. For an old macadam, penetrating qualities may be desirable, in which case an MC-1 cutback may be used. The required quantity of crushed rock is then placed in a windrow on the road surface. The rock may be 2″-¾″, 1½″-½″, 1″-½″, or ¾″-⅜″, depending on the thickness of the mat desired. If the mixing is to be done by the blade method the material is spread evenly over the surface and an application of RC-3 or 4 made, after which the material is mixed back and forth across the surface until the crushed rock is thoroughly coated with bitumen. The mixture is then spread evenly over the surface and rolled. The wheels of the roller are kept wet during this operation. Key rock is next distributed evenly over the surface and rolling continued. Any excess of key material is removed before the final application of cutback and cover material.

For priming old concrete surfaces 1/10 to 1/8 gallon per sq. yd. of either RC-2 or RC-1 is sufficient. Old macadams may require 1/4 to 1/10 gallons per sq. yd. and MC-1 is specified to give depth of penetration.

The bitumen required to cover the crushed rock with a thick film may vary between ⅜ and 1 gallon per sq. yd. depending on whether the resulting mat is to be ¾ inch or 2 inches in thickness.

The final seal is accomplished with an application of cutback in the amount of ¼ to ½ gallons per sq. yd. followed by about 50 lbs. of cover material varying in size from ½ to ⅛ inch.

If the old pavements to be resurfaced are too uneven, it is desirable to place a leveling course before the regular mat is applied.

This type of surface is truly a bituminous macadam and has given remarkable results when properly constructed. It requires rock, hard and tough enough to resist the weight of the roller without pulverizing. It has high stability and no high pressure control system is necessary. It is a high void mixture in which a thick binder is desirable, and must be placed on a strong dry stable base. On wet bases water can enter the mixture from the bottom. The top is very well sealed against the entrance of water from the surface.

Retread surface has given results that compare favorably with bituminous concrete and rock asphalt. The type is not very largely used in the mountain states, but has been used to a large extent in the middle western and eastern states. The predominance of suitable gravel in the mountain states makes the close graded type more favored.

The open graded type when placed on the proper base performs well in the presence of moisture. The fact that some moisture enters the mixtures does not cause instability as in the close graded mixtures. Each type has its place in locations where materials and climate are favorable. In most cases the available aggregate and the condition of the old surface to be improved, decide the type of surface most suitable. For a given thickness of mat the close graded type is usually cheaper to construct.

MINERAL AGGREGATES FOR DENSE GRADED BITUMINOUS MIXTURES

**By J. W. Kushing, Research and Testing Engineer,
Michigan State Highway Department**

The construction of bituminious surfaces of the dense graded aggregate type generally necessitate the use of local materials, for our mineral aggregates. Any attempt to standardize on the requirements for the mineral aggregate or in the method of construction in such a manner as to hinder their use may defeat the economy of such a type.

From past experience, in the construction and research of road surfaces with dense graded bituminous mixtures, engineers have found that certain quality and grading characteristics in aggregates are desirable to produce satisfactory mixtures and likewise certain control measures must be adhered to in their use if the completed work is to successfully resist the effect of traffic and weather. Satisfactory results in construction experience, aided by laboratory research is gradually establishing limitations within which we may expect success and outside of which, success will be doubtful.

It was intended that this paper be comprehensive and not limited to the data or experience in any one state or area. With this in mind, we have secured information from the various states and from the Province of Saskatchewan by means of a questionnaire.

A complete summary of replies received to this questionnaire are appended to this report.

In considering the value and relationship of quality, grading and control of the aggregate, frequent reference will be made to practices as shown in this summary.

Quality.

The quality, or the physical properties of a mineral aggregate for bituminous mixtures, is determined by its ability to resist **traffic abrasion and crushing in construction, internal stability,** and **resistance to weathering.**

Traffic Abrasion and Resistance to Crushing in Construction.

This quality for gravel and crushed stone is determined by the standard laboratory tests, such as Deval Abrasion, Los Angeles Rattler, Page Impact, and Lithological Count in which emphasis is placed upon the soft and non-durable particles.

Gravel—Eleven of the twenty states reporting the use of dense graded aggregate with MC and SC bitumens, use the Standard Abrasion test to limit the use of inferior aggregates. One state uses the Los Angeles Rattler making a total of twelve states restricting inferior gravel aggregates by an abrasion test.

Of the remaining eight states which do not require the Standard Abrasion test, three restrict the amount of soft and non-durable particles allowable, which means that a total of fifteen states out of twenty control the quality of gravel aggregate by these two tests. It appears, therefore, that the use of such tests are necessary and justified for the determination of quality aggregates and for low cost roads. Obviously, no definite test limits can be set which will apply to all regions; they will vary for each region; depending upon what type of materials are economically available. The data indicates that the abrasion test limits may vary, in most cases, between six and twenty-five on uncrushed material and up to thirty on crushed aggregate. The Los Angeles Rattler limits are placed at 45% maximum loss for five hundred revolutions. The limits on soft and non-durable particles vary between five and ten per cent.

Stone—Eleven of the fifteen states reporting the use of crushed stone, specify limits on the Standard Abrasion test, while one other state specified a limit on the Los Angeles Rattler test, making a total of twelve out of fifteen controlling the quality of stone aggregate. The abrasion test limits vary between five and fifteen with the largest number of states reporting a limit less than eight. The Los Angeles Rattler limits for stone are placed the same as for gravel. The toughness test as determined by the Page Impact machine is required only by one state. It appears that this test has not been given consideration as being necessary for measuring quality of aggregate for this type mixture.

Internal Stability.

Besides resistance to abrasion and the chemical strength, the particles must be capable of interlocking with one another, that is to say, possess internal stability. A spherical shape gives the maximum strength and minimum interlock; and a flat and pointed form gives the contrary, with a resistance to compaction under the construction equipment. The shape and character of the fine aggregate should also be given consideration in this connection. Although this property was not considered in the questionnaire, we believe that it merits thought from a standpoint of stability and non-skid properties in the finished surface, consequently the surface of the particle, whether sand, stone or gravel, should not be mainly smooth or too porous. It should be preferably rough to assist in the holding of the bituminous binder in addition to its surface tension.

The internal stability of crushed coarse aggregate is dependent upon its ability to interlock enabling superimposed loads to be more readily transmitted to the sub-base without displacement. This has been favorably considered by all states reporting in this investigation and it is the general opinion that crushed material will aid in increasing internal stablity. However, only five states out of twenty have made provision in their specifications to demand crushed materials in aggregates for low cost construction. Several other states require all oversize materials to be crushed or prefer crushed material in the aggregate which indicates the trend to increase the resistance to displacement by traffic on this type of road construction by the use of crushed materials. The states which require crushed materials have set minimum limits between 25 and 50 percent. It appears, therefore, that although no general requirement for crushed material can be set up, steps should be made to improve dense graded aggregate by including a minimum crushed aggregate requirement.

Although these trends are obvious, no definite test procedures for measuring the effect of crushed particles on internal stability has been indicated by the questionnaire. However, a brief survey of existing literature reveals that several types of stability tests have been used in the past for determining stability of bituminous mixtures. California uses the Hveem Stabilometer. (This test is described in Part II—Proceedings of the Fourteenth Annual Meeting, Highway Research Board.) Several other states use a modification of the Hubbard-Field stability test while Michigan has made some preliminary stability studies with a modification of the Hveem Stabilometer. (Refer to "Stability of Granular Mixtures" Proceedings A. S. T. M., Vol. 35, Part II; "Internal Stability of Granular Materials," Proceedings A. S. T. M., Vol. 36, Part II. It appears that a test of this nature could be used to measure the effect of crushed particles in a dense graded mixture but additional research work along the lines indicated will be required before the merits of crushed material in dense graded bituminous mixtures can be established.

Resistance to Weathering.

A fundamental quality of a bituminous mixture in addition to structural and mechanical strength, is that it be waterproof and resistant to weathering. Properties of aggregates to resist weather are determined by such tests as **soundness, water asphalt preferential test** and **swell test.** The latter tests being used primarily for fillers.

Soundness—This soundness test is an accelerated test developed to measure the resistance of an aggregate to repeated freezing and thawing. Although this test is not used by the majority of the states, three states indicate the use of this test for the detection of inferior aggregates. It is questionable whether this bituminous construction of the type under consideration if a rigid soundness requirement is justified. Unless unusual types of materials which easily disintegrate are encountered, it is doubtful as to the value of this test due to the self-healing qualities of an SC or MC bitumen.

Preferential and Swell Test—It is recognized that well constructed bituminous surfaces are essentially waterproof, but it must be remembered that the surface tension relationship of binder, fine and coarse aggregates and water, are such that water tends to enter between the mineral aggregate and the binder if it has the opportunity, because of preferential absorption. This property may be determined to some extent by the Water Asphalt Preferential Test and Swell Test. These tests are being used, or planned to be used, by over half of the states participating in this investigation. More emphasis has been placed upon the Swell Test since it has been found that apparently satisfactory fillers may be rejected by the Water Asphalt Preferential Test. The tendency to not recognize the former test may be due to economic factors which have necessitated the acceptance and rejection of fillers on the basis of the Swell Test which is less severe. Due to the diversity of opinion concerning the Water Asphalt Proferential Test, more investigational work is necessary. Observations of pavements using both satisfactory and unsatisfactory filler, on the basis of this test, over a long period of time under similar traffic and weather conditions may establish whether this test measures a quality which insures long life to oil aggregate mixtures.

In considering these tests and results obtained with various type of fillers, the question arises whether the addition of some material which will improve this absorption quality in the mix is necessary. The question was asked in the questionnaire as to the advisability of a portion of the aggregate being calcareous in nature. In answer to the question, there was quite a divergence of opinion. Also the technical information on this subject seems rather controversial and the whole subject of preferential adsorption needs more clarification by further research.

Thus, in summing up the quality tests it is apparent that the physical characteristics of a material to be chosen for this type of surfacing are very important from the standpoint of quality and durability and consideration should be given to the properties of resistance to abrasion, structural strength, shape and physical chemical action. However, it must be remembered that with low cost road construction, economy has necessitated a divergence in the emphasis placed upon various quality tests. Therefore, it appears that the engineer must use good judgment in the selection of tests to determine the quality of material which can be economically used in the area under consideration.

Grading.

The stability of a dense graded mixture also depends upon grading. Gradings used for this type of work in various states are shown in the chart attached to this report. The ideal grading of the fine and coarse aggregate in dense graded bituminous mixture is that in which the final mixture shall almost attain maximum density thus resulting in maximum stability with minimum use of binding material, thereby obtaining an economical low cost surface. There is a growing tendency to the development of gradings which result in a surface not necessarily of maximum density but one of a coarser texture which is more flexible and yielding to surface impact without permanent displacement. These type of gradings serve to develop a more nonskid surface which is desirable with present high speed traffic.

A study of the grading curves indicates that a maximum size of one inch is preferred in this type of construction, with a wide range in amounts of material passing smaller screen and sieves. In no case is there more than 15 percent passing a number 200 sieve. However, some states do not feel the necessity of including the finer fraction, perhaps in some cases due to economic reasons. Also it has been pointed out in the answers to the questionnaire that high percentages of fillers may produce critical mixtures which are subject to bleeding in warm weather.

Tentative Dense Graded Specifications.

It appears from a study of quality requirements and grading used by various states that no definite limits can be given. It is evident that economic factors have a direct relationship upon what tests will be required to determine the quality and gradations of the materials used for dense graded aggregate mixtures. However, trends are indicated and thus a general specification can be formulated which, although, may not be used as a whole in any specific area, tends to indicate the qualifications and gradings of materials which will give satisfactory dense graded bituminous mixtures. These specifications are as follows:

(1) The abrasion shall be less than twenty-five for gravel and less than ten for stone aggregates.

(2) At least twenty-five percent of the coarse aggregate (retained on the ¼″ screen) shall be crushed.

(3) The material shall not contain over ten percent by weight of soft and non-durable particles.

(4) Not over two percent clay or mud balls shall be permitted in the aggregate.

(5) The mineral filler shall be of such quality as to satisfactorily pass the Swell Test which will be made upon a composite bituminous mixture.

(6) The grading of the aggregate shall be such as to fall within the grading zone indicated in the gradation curve. Attention is called to the fact that an MC bitumen may give more satisfactory results than an SC bitumen in connection with the coarse and more open gradings.

Field Control.

The control of quality and grading of mineral aggregates in the construction of dense graded bituminous mixtures is important and essential as with any type of construction or maintenance. It is of a two-fold nature involving both laboratory and field testing. These two factors are not separate and successful control depends upon the proper relationship existing between laboratory and field inspection forces as experience has shown that control of aggregate gradings are made more positive by a double check between these two organizations.

When samples are sent to the laboratory for testing of physical properties in a material survey for a given source of mineral aggregate, the field control is confined to grading, and determination of objectionable materials by visual inspection. Further control will be obtained by the plant inspector who handles mix inspection which is not within the scope of this paper.

A traveling field inspector who maintains contact with the laboratory should visit construction projects frequently in order to observe and advise in regard to difficulties encountered by the field inspector.

Control of Grading—Gravel deposits of glacial or stream origin, in many cases, are non-uniform. They may vary from fine to coarse in comparatively short distances. This non-uniformity of the deposits makes the production of a specification gravel very difficult for many portable gravel plants.

Several cases have been noted where within 200 feet the character of the deposit changes from a high pebble deposit to a high sand deposit. Several methods have been used successfully to cope with these situations. One method is to open both types of deposits and haul the deficient material to the gravel plant in order to adjust the aggregate grading. Another method is to place a rejector on the plant and remove excess material at the gravel plant. This rejected material should be stocked, since it may be required to correct the grading if the character of the material in the gravel bank changes during the production period.

Variations in grading occurring at the plant can be further reduced during the stock piling of the aggregates. The use of a layer method of building the stock pile enables small variations to be corrected and insures uniformity of the aggregate used at the bituminous mixing plant. The end dump method of building a stock pile should not be permitted as excessive segregation of coarse material will result. In some cases, a non-uniform stock pile must be handled in the field. The use of a clam shovel is very desirable for this work since a remixed stock pile can be easily constructed from the original pile prior to loading of aggregate for consignment to a project.

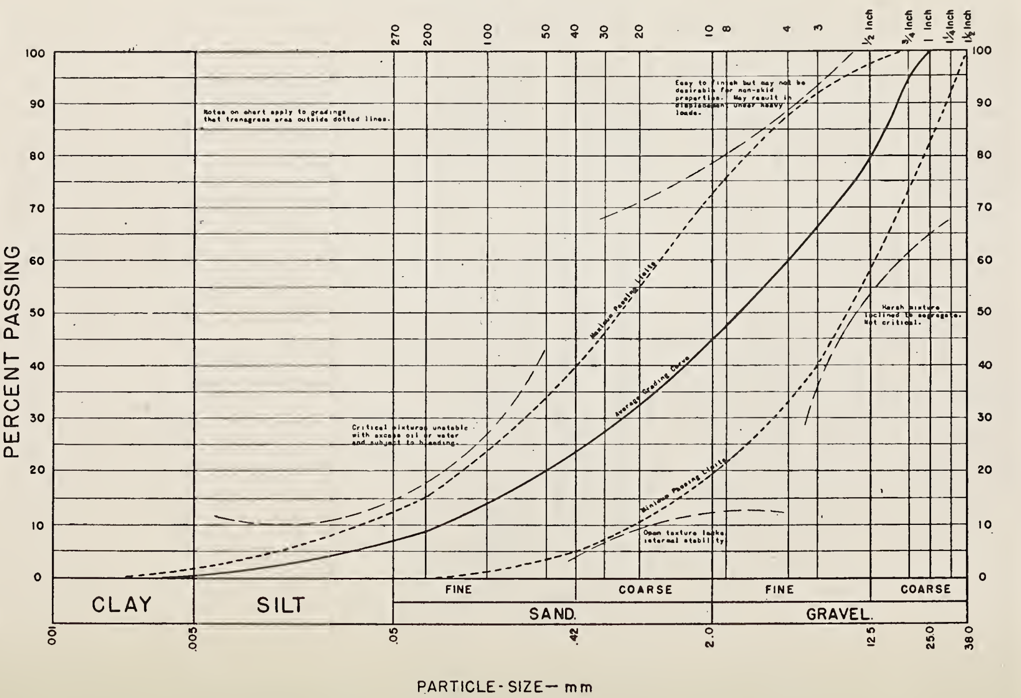
Thus, field control of the grading of aggregates consists mainly of screen analyses. This means that a gravel inspector should be assigned to all aggregate plants to insure the production of specification materials. The result of the tests must be interpreted by the inspectors and control methods suggested which will blend various grading materials together in such a manner as to produce specification materials.

Conclusion.

In the choice of mineral aggregates for dense graded bituminous surfacings, the specifications for materials; the design of the mix and construction methods will be dependent upon cost, quality, durability and availibility. Recourse must be had to information on the results obtainable with the materials and methods used. It is assumed that the results obtained by the various states answering the questionnaire were satisfactory. If there is a variance in opinions it is probably due to the fact that different emphasis has been placed upon one of the above economic factors. Generally cognizance of the principles regarding aggregate which have been covered in this paper will aid in successful results, but it does not necessarily hold that specifications used in one locality will guarantee satisfactory results in another.

GRADING CHART
FOR
MINERAL AGGREGATES IN DENSE GRADED BITUMINOUS MIXTURES

PARTICLE GRADATION–SCREEN SIZE.



MINERAL AGGREGATES FOR DENSE GRADED BITUMINOUS MIXTURES.

AS USED BY VARIOUS HIGHWAY DEPARTMENTS

COMPILED BY RESEARCH & TESTING DIVISION OF
MICHIGAN STATE HIGHWAY DEPARTMENT

August, 1936.

FUNDAMENTALS OF GRAVEL BASE CONSTRUCTION

By A. E. Stoddard, Assistant Engineer of Materials and Tests, Iowa State Highway Commission

When I consider the mass of literature regarding low cost road surfaces and the many and varied opinions of engineers concerning materials and methods, I am reminded of this statement made by the late Will Rogers: "There ain't anybody who knows more than anybody else. They just know different stuff."

One of the points on which engineers have had divergent opinions has been the thickness of pavement. As early as 1901 in the annual report of the Massachusetts Highway Commission, Mr. W. E. McClintock, chairman, made the following statement:

"The Commission has estimated that non-porous soils drained of ground water, at their worst will support a load of about four pounds per square inch, and having in mind these figures, the thickness of broken stone has been adjusted to the traffic.

"On a road built of fragments of broken stone the downward pressure takes a line at an angle of about 45 degrees from the horizontal and is distributed over an area equal to the square of twice the depth of the broken stone. If the division of the load in pounds at any point by the square of twice the depth of stone in inches gives us a quotient of four or less, then will the foundation be safe at all seasons of the year. On sand or gravel the pressure can safely be put at 20 pounds per square inch.

"Acting on this theory the thickness of the stone varies from four to 16 inches, the lesser thickness being placed over good gravel and sand, the greater over heavy clays and varying thicknesses on other soils. * * * "

The surfacing referred to was of the macadam type which obtains its stability from interlocking of coarse particles. In his remarks regarding road design one author states: "Macadam foundation failures are due to insufficient depth, insufficient consolidation during construction and poor grade of filler. The matter of filler is very important. Coarse sand and pea gravel or stone screenings are preferable, and earth or loam **that softens when wet should never be allowed.**"

This adverse opinion of soils as filler has been entirely reversed since more detailed studies of the finer sizes of particles have given better understanding of their functions and have permitted the use of this material with very satisfactory results.

Engineers have begun to design rigid pavements on logical mathematical basis for relationship between the transverse strength of the slab, the load and the subgrade support. Flexible pavements do not possess sufficient beam strength to warrant inclusion of this element in any mathematical expression of the distribution of concentrated wheel loads to the relatively light pressures which subgrades soils in their worst condition can safely withstand. With the development of low cost roads various engineers have proposed formulas for this statement of equilibrium which we call design. At the conference in Butte last year, Mr. McCoy of the Bureau of Public Roads named for you three of these formulas, which express the relation between the wheel load, the area of contact of the wheel on the road surface, the thickness of the surfacing which effects distribution of the pressure and the safe bearing pressure on the subgrade. These formulas were proposed by Harger & Bonney, Professor Downs of West Virginia and Bernard E. Gray of the Asphalt Institute.

These formulas were given in proceedings of last year and will not be repeated here, but for convenient reference will be listed with other data at the end of this paper.

These formulas differ from each other in only one detail: this is the shape of the area of contact through which the load is applied. Harger and Bonney assume that the load is applied through a line, the length of which is the width of tire "T."

Professor Downs assumes the load applied at a point.

Mr. Grey assumes the load applied over a circular area, the radius of which he designates (e).

All three formulas show that the load supported will be proportional to the square of the thickness of the surfacing. All three formulas assume the distribution of the load through the road surface at an angle of 45 degrees from the vertical. This simplifies the formula, but according to Mr. C. A. Hogentogler, in an article on "Soil Road Surfaces" published in Public Roads for February, 1935, the angle of internal friction on either sand or cemented sand and gravel is only 34 degrees. If this angle be substituted for the 45 degrees assumed, the required thickness will be increased by approximately 1.483. All the formulas also assume uniform support of the subgrade. Mr. Grey points out that because of the flexibility of the surface, the subgrade and surface are in constant uniform, intimate contact. He also points out that because of the shearing force exerted at the edge of a loaded area the pressure may be assumed to be uniform over the area. It is true that tests of Bankleman of the Bates Road and Housel in Michigan indicated the presence of "perimeter shear" when the load was applied through a surface sufficiently rigid to effect a reasonably uniform distribution. This was observed in the difference in unit bearing power obtained with the loading of areas of different size, all of which were rigid. To my knowledge, in none of these tests were any flexible surfaces loaded.

With rigid pavement slabs the supporting power of the subgrade, as computed by Mr. Westergaard, is proportional to the compression of the subgrade. It is greatest in the area in which the slab deflects the most and decreases gradually to zero at the point of counterflecture where the deflection is zero. Numerous investigators have made measurements of rigid slabs under load to determine the shape of the deflection curve. Pressure cell measurements on the Bates experimental road in Illinois under pavement composed of macadam base with 2 and 3 inch Topeka top, indicated that there was very little beam action and that the load was transmitted by direct pressure to the subgrade. Unfortunately the tests with this type of surfacing were of very limited extent. Before any design formula can take into consideration the beam action of the bituminous surfacing or of the stabilized base, it will be necessary to determine the extent to which it is effective and, if possible, determine the shape of the deflection curve in the area which contributes to the wheel load support. Such tests would need to be obtained throughout all the varying range of moisture content which would be encountered.

In flexible surfaces since the distribution of the load depends upon the internal friction of the granular particles and not upon beam action, it seems more logical to assume that the load will not be uniformly distributed but will be represented by a solid volume, the maximum ordinate of which is equal to the safe bearing pressure on the soil and tapering to zero at the edge of the area. For Professor Downs' and Mr. Grey's formulas such a distribution of pressure would reduce the supporting power for a given thickness to about one-third the previous figure or require approximately 1.73 times the depth. For Harger & Bonney's formula such a distribution would reduce the supporting power to less than one-half of the previous figure, the exact reduction depending upon the relation between the width of tire and the depth of surfacing.

In addition to the effect of changes in the basic assumptions, in order to apply the formula it is necessary to determine what will be the safe bearing load for the subgrade soils to be encountered. This is by no means a simple matter, for soil characteristics are affected by the infinite variation of the proportions of the component materials.

Each combination is affected differently by variations in moisture content. With road locations in rolling country the grade line may intersect a number of different soils within a short distance. The actual bearing power of the subgrade may be determined by use of the Proctor needle, but to correctly determine the ability of the subgrade to support the load it will be necessary to extend the soil survey to a depth which will insure that the subsoil layers will be capable of withstanding the pressures which will be transmitted to them.

In the article in Public Roads by C. A. Hogentogler, to which we previously referred, he shows the theoretical supporting value of soils when loaded in a narrow line of infinite length, similar to the values reported by Mr. McCoy last year. These are as follows:

Clay Liquid	400 lbs. per sq. ft.	2.78 lbs. per sq. in.
Clay very soft	860	5.96
“ soft	1850	12.8
“ fairly stiff	4970	34.5
“ very stiff	12,490	86.7
Sand dry	270	1.85
Cemented Sand and Gravel	17,340	120.4

The correct classification of the subgrade material encountered and assignment of correct bearing value are still matters of judgment and experience in knowing what will be the “worst condition” of the materials encountered.

Theoretically it should be most economical to construct a base in which the stability will vary throughout the depth from high bearing pressure needed just under the surface to the low bearing pressure permitted on the subgrade.

From practical consideration it is more desirable to vary the pressure on the subgrade by variation in the thickness of the base. Except when conditions require extreme thickness the same composition and stability will be maintained throughout. Common practice in States of the Middle West consists of thicknesses of base from 3 to 12 inches. Iowa is probably using the least of all, since we are stabilizing about 2000 cubic yards of aggregate per mile, most of which is used in strengthening the edges of the surface to be treated. The net compacted thickness will probably not average more than 3 inches. However, prior to placement of base, portions of extremely weak subgrade are given frost boil treatment.

This frost boil treatment generally consists of placement of a porous layer of rock or gravel which will interrupt the capillary flow of water. Drainage is provided for these porous layers. If at any time the drainage fails to function, the porous layer will become a reservoir which will supply an excess of water to the subgrade adjoining the treated area. The experience of the Minnesota Highway Department is mute evidence of this fact for in successive years it has been necessary on many sections to extend the frost boil treatment at each end of the original area. It is the writer's opinion that an impervious layer in which it is not possible to have sufficient capillary flow to cause instability will be more effective treatment than a porous layer which may act as a reservoir for water. To this end it would be much better to increase the thickness of the stabilized layer of base course rather than the present methods of frost boil treatment.

The width of this type of construction is generally greater than for rigid pavements. Where a 20-foot concrete pavement is standard, the stabilized base is usually constructed to widths of 22, 24 and 26 feet. Theoretically from the standpoint of design the base should exceed the width of surface to be used by at least two times the depth. Extra width also tends to avoid traffic wear on the unprotected edge of surfacing. Thickening of the edges will also add considerable stability to the surface.

Where the new surface is being built "on top" of an existing surface it is necessary to use side forms to secure consolidation of the mixture at the edges and at the same time maintain proper riding qualities of the surface. Where the base is built in trench section the earth shoulders furnish lateral support during consolidation. The trench section somewhat restricts operation of preparation and mixing of materials on the road surface but does not affect placement of plant or pre-mixed surfaces.

The stabilized soil-sand-gravel surfaces are accurately proportioned mixtures of materials of every size from the customary maximum of 1" to colloids. According to the Progress Report of the Committee on Stabilized Soil of the Highway Research Board, the functions of the various materials are as follows:

"The coarse aggregates and coarse sands furnish hardness and structural strength. Fine sand adds an embedment support to the coarse sand. Silt acts as filler to prevent the granular particles from rocking. Clay and colloidal particles provide pores minute enough to cause the connecting moisture films to have high cohesion."

Webster's Dictionary says that cohesion is that form of attraction by which the particles of a body are united throughout the mass whether like or unlike. The most common demonstration of cohesion which comes to mind at present is shrinkage and increase in strength of clay products as they are dried before firing, or of the ordinary gumbo soil as it shrinks into large cakes on drying.

TABLE I

Composition of Final Mixture of Graded Aggregate

Sieve Size	Per cent by Weight	
	Min.	Max.
Passing 1″ sieve	----	100%
¾″	80	100
⅜	50	90
No. 4	40	75
10	30	55
40	20	35
200	10	20

The fraction passing the No. 200 sieve shall not be more than two-thirds of the fraction passing the No. 40.

The detailed sieve analysis limits is shown in Table 1. These percentage limits when plotted against the log of the sieve opening produce the shaded area within the curve of figure 1. These data have been given widespread publicity by the Calcium Chloride Association.

In addition to the limits of the gradation of particle size, satisfactory mixture according to their specification will also have the following characteristics:

> The fraction passing the 40 mesh sieve will show a plasticity index of 4-12.
>
> The sum of percentage of the material passing the

40 mesh sieve and the plasticity index shall not exceed 40.
The liquid limit of this fraction shall not exceed 35%.
The fraction passing the No. 200 sieve shall not be more than two-thirds of the fraction passing the No. 40 sieve.

The report of the Highway Research Board further indicates that the plasticity index of the mixture should be varied somewhat according to the climate to which the surface will be exposed. Their recommendation follows:

> "Generally plasticity indexes of about three or less indicate sufficient binder cohesion for roads to be constructed in locations subject to unusually wet conditions; 4 to about 8 for conditions of average moisture and 9 to 15, inclusive, only for dryer or arid conditions. Plasticity indexes exceeding 15 indicate soils not suitable for this type of construction."

Prompted by economy of the use of all available materials common practice in many cases has used both the mineral aggregate from the road surface and the subgrade soil for the binder. Since the grade line is fixed at bridge structures and railroad crossings, construction of the new surface at or near the present grade is generally preferred. This permits correction of small irregularities and may provide materials for construction of shoulders to reduce the crown of the roadway when a bituminous top is to be placed. Material removal from the road surface must be made as uniform as possible in quantity and character in order to secure uniform finished mixture. The quantity is most easily controlled by means of portable orifice or Gopher Trap which will produce a uniform cross section of windrow. Other materials added to the mixture must also be proportioned in the same way. Since laboratory tests results are reported on weight basis, it is necessary to convert the data to volumetric proportions, using the unit weights of materials as placed in the windrow.

Soil binder must be thoroughly pulverized to function properly in the mixture. Equipment for this purpose will vary considerably with different contractors. When the clay is pulverized on the roadbed, the disc, the tooth harrow and other farm equipment for breaking clods and preparing the seed bed will serve to pulverize the binder. One of the old drags made of three planks lapping each other about three inches is quite an effective pulverizer. One contractor used what is known as a Roto-mix, which consists of semi-cylindrical hood over the mold board of a motor patrol with a single shaft carrying paddle wheels mounted in front of the blade and driven by a separate power unit. This machine was a very effective pulverizer, but on windy days caused some loss of dust. A light roller is also effective in the initial stages of pulverizing.

Various other methods have been used. When the soil is not pulverized on the roadbed, the clay may be partly pulverized in pit before removal to the road site if the deposit is dry enough. In such an operation the pit would probably extend over a considerable area and a thin layer of the material be thoroughly disced and given preliminary pulverizing by any of the equipment mentioned above. In some projects in Minnesota the soil binder prepared in this manner was then passed over shaker screens to remove the oversize and the finer sizes transportated to the road where it is placed on top of the gravel to complete the pulverizing and mixing.

The Pioneer Gravel Equipment Manufacturing Company of Minneapolis has developed a clay shredder which, without drying, breaks up the clay quite fine by passing it between two rolls which are operating at vastly different speeds. The shredded clay is then passed through a proportioning device which delivers it to the mixer with the gravel in the desired proportion.

In any of the pulverizing operations, good drying weather is absolutely essential, for without it the clay cannot be sufficiently pulverized. On one project using a plant mixed material, the clay was delivered dry and completely pulverized from a commercial brick and tile factory. One or two contractors have proposed wet mixing as with wet process of cement manufacture, but to my knowledge none of them have tried this method. Clay retains its moisture and loses it slowly so that the reduction of moisture content in mixtures which are too wet would be much more difficult than raising the moisture content of mixes which were dry.

Originally it was recommended that the soil be pulverized until 90% would pass the 8 mesh sieve. At this point, however, the soil becomes practically fluid and there may be considerable loss by the dry material flowing off the road surface, or being blown away by the wind.

Present recommendations of the Calcium Chloride Association specifications require pulverization only until 80% of the soil will pass the 4 mesh sieve. These limits were set because it was found that particles passing the 4 mesh sieve were usually broken down sufficiently during the mixing with the aggregates. However, with proper equipment and but very little more work pulverization until at least 90% passes the 4 mesh sieve may be secured and this is felt to be a more desirable limit. The presence of a small amount of moisture in the soil renders it much more easily pulverized. Also the incorporation of some sand in the early stages of pulverizing helps to break down the small clods which, when thoroughly dry, act like so many ball bearings. When soil is sufficiently pulverized it is mixed with the aggregates by blading and discing the windrow in a manner similar to mixing bituminous treated surfacing materials. Thorough mixing will continue the pulverizing and reduce and distribute the soil to the desired condition.

When the materials from the road surface are not incorporated in the mixture, the proportioning, drying and mixing may be done on the road by bringing on all the ingredients in the desired proportion, or by pre-mixing the materials. In a few instances deposits have been found which with but slight alteration in excavation of the material would conform to the requirements for the finished mixture. The mixing may be accomplished by the same methods and with the same equipment used for mixing concrete, but more efficient mixing is accomplished in the pugmill type mixer.

Whether the material will be mixed on the road or premixed will be influenced by several factors. When either the soil binder or the aggregates or both are available in the existing road surface, it will generally prove more economical to mix the material on the road surface.

The thickness of surfacing to be placed will also influence the selection of road or plant mix. About 2000 cubic yards of materials per mile of road is all that can be conveniently handled on roadways of ordinary width. Where the quantity involved is greater than this, it should be placed by completely separate operations in two or more layers.

Plant mixing is particularly advantageous where available deposits require but little treatment to meet the required composition, in city work where the shade from adjacent trees and buildings would obstruct the drying and where the dust from pulverizing would be a public nuisance. It is also advantageous in working the irregular areas of street intersections. In plant mixtures the moisture is also added at the mixer so that the mixture is ready to compact when delivered on the road.

One project of about three miles of city streets was constructed in the city of Ames last fall using pre-mixed material.

In the final stages of the mixing process, sufficient moisture must be added to put this mixture in a proper condition for compaction. This will usually require 5 to 8 per cent by weight of the total mixture. The moisture should be sufficient to raise the portion of the mixture passing the 40 mesh sieve to the plastic limit. The moisture content has a very definite effect on the density which can be secured by any given method of compaction. In either too dry or too moist a condition the mixture cannot be consolidated as well as at just the right moisture content. This effect can easily be observed by checking the unit weight of samples compacted at various moisture contents. Curves of the relative densities for various moisture content behave exactly like Mortar-Voids curves for cement mortars.

In some laboratory experiments it was found that in mixtures which differed only in the character of the soil binder and in which the methods of mixing, handling and consolidating were duplicated as exactly as possible, the density or weight of dry soil per unit volume of consolidated mixture increased as the moisture content increased up to a certain definite point from which the density decreased with further increase in moisture. Figure 2 shows the curve of air and water voids for a typical mixture. The characteristics of the mixture and the materials of which it is made are shown at the end of the paper.

The desired moisture content must be maintained during compaction. To prevent the subgrade from taking moisture from the mix, the subgrade should be sprinkled and the mixture placed while the subgrade is still moist.

Consolidation of the mixture is an important item. Again the procedure must be varied to fit the equipment to be used. In general the base course should be placed in layers not exceeding three inches in thickness, where smooth steel surfaced rollers or pneumatic tired rollers are used for compaction. The pneumatic tired rollers seem to be more efficient than the smooth steel tired rollers in consolidation of the surface, but a surface finished with the pneumatic tired rollers will not be as smooth as one finished with a steel tired roller.

Mixtures with the higher plastic limits at certain moisture contents tend to stick to steel rollers, but may be easily compacted by pneumatic tired rollers.

With a sheeps foot or tamping roller a deeper layer of material could be compacted because this roller consolidates the course "from the bottom upwards." The depth of layer should not be as great as the length of prongs or "feet" for otherwise the pressure would be reduced by greatly increasing the bearing surface. Too plastic a mixture would probably fill up a sheeps foot roller by adhering to the "feet." This type of roller has not been tried on any stabilized surfacing in Iowa.

I have recently seen a roller produced by the Parsons Company, Newton, Iowa, for use by the PCA on stabilization experiments. This roller is composed of about 12 cast iron wheels, each with a rolling face only 2½ inches wide with a space about 3½ inches between them. The wheel is solid and for a radial distance of about 10 inches from the face, the thickness increases, giving a trapezoidal section. The roller is equipped with surface cleaners and bayonet cleaners between wheels. Also on the rear frame is a rake, which can be adjusted to smooth out the ridges left by the rolls. This roller should be effective in consolidating a layer of considerable thickness. We hope to have opportunity to see it in operation on work this season. At the present time only one such roller has been built.

From laboratory studies it is apparent that with mixes of uniform moisture content the degree of consolidation effected will depend upon the amount of work done, or the number of passes of the roller. This effect is clearly shown in Figure 2 by the points along the line CD. The figures indicate the relative compaction by the number of passes of a 30-pound laminated roller over the specimens which were 2x2x14 inch prisms cast horizontally in five layers. The roller was 4 inches in diameter, in two sections and arranged with four wheels or discs on each section to cover the entire width of surface. During the rolling the mold was placed in a supplemental holder which permitted the roller to be passed entirely over the specimen without contact with the form.

To insure satisfactory compaction it will be necessary to compare results secured by field methods with results obtained by some standard method of compaction. A convenient basis of comparison is the consolidation by tamping or raming the material into a mould such as is used in the Proctor method for checking the consolidation of soils and earth dams. It is not possible to use the Proctor needle in checking consolidation of mixtures containing gravel and stone. For such mixtures it is not usually possible to remove intact a specimen from the road surface. The unit weight of the compacted surface can be checked with a fair degree of accuracy by measuring the hole from which the sample has been removed. This can be done by measuring the quantity of a liquid, such as lubricating oil, required to fill the hole. Water may also be used for this purpose by pouring it inside a very thin rubber sack. Dry sand has also been used.

The use of salts such as calcium chloride or sodium chloride to maintain a more uniform moisture content has been highly recommended by companies with these materials to sell. When the base or road surface is to be left uncovered, or is to be used by traffic for a period of time as when the surface is compacted by traffic, it is essential to retain proper moisture content. Either sodium or calcium chloride are effective in retaining moisture during handling and compaction because the salt solutions have lower vapor pressure than water alone.

The salt may be incorporated in the mixture or applied to the finished surface. When no salt has been incorporated in the mixture the amount applied to the surface should not be less than a pound to one and one-half pounds per square yard. Where salt is incorporated in the mixture at least 10 pounds per ton (or .5 lb. per square yard per inch thickness) should be incorporated, and in addition the finished surface should be given an application of .6 pound per square yard.

Kansas also requires an application of salt to the surface of the sub-base before moistening preparatory to compaction of the stabilized base mixture.

In addition to the salts mentioned, many other materials may possibly be used to increase the impermeability of the mixture. Among these are various oils of the SC and MC classes, and emulsions of various kinds. It seems quite reasonable that treatment with some bitumen would make these mixtures much more resistant to change in moisture content. The bitumen might be used in treating the surface of the sub-base, or in treatment of the mixture itself. Since the mixture must contain considerable moisture at the time it is ready for treatment, it is only reasonable that bitumen in emulsion form would be much more readily incorporated into the mass and would diffuse throughout and coat the particles better than bitumens in other forms. The Missouri Highway Department has done considerable work in the treatment of bases with bitumen in the presence of soaps and in emulsion forms. They have also conducted experiments in the newer method of application known as sub-oiling. I believe this method will be discussed in connection with treatment of soils.

The Portland Cement Association is also promoting the stabilization of some soils by the addition of Portland Cement. This method of stabilization has been used in some experimental roads in South Carolina and I believe some sections are being constructed in Indiana and Illinois. The Portland Cement Association has been conducting an extensive laboratory study of soil and cement mixtures.

A properly stabilized gravel surface can be smoothed and worked by the use of the ordinary maintenance equipment only when the surface has been thoroughly wetted. In the dry condition the blade will not cut the surface. Traffic does most of the damage to a stabilized surface by splashing through any pools of water which collect on the surface. This washing action puts the clay binder in suspension in the water and permits the aggregate to be displaced. Holes of this type must be corrected by blading when the surface is wet, or must be cleaned out and patched with stabilized mixture just as you would patch a bituminous surface with a bituminous mixture. So far most of the studies of stabilized mixtures have consisted of analysis of various ingredients and observation of experimental sections. While these methods of examination yield considerable information, the physical characteristics of mixtures need examination in numerous details. Application of tests found effective on other materials may bring to light characteristics of which we now know little.

The California Highway Department has been applying a stability test to this material similar to the Hubbard Field test for asphaltic mixtures.

The Missouri Highway Department has been studying stabilization with bituminous materials including emulsions, oils of MC and SC grades with water and special reagents to promote dispersion and linkage of oil in the soil aggregate systems.

Michigan is investigating the Portland Cement stabilization.

In our own state we have applied some of the same methods used in the studies of voids in Portland Cement mortar. In Figures 3 and 4 we have the transverse and compressive strengths of two soil aggregate mixtures. You will note that at the moisture content at which the material was most readily compacted the transverse strength was zero and also at 75% of the moisture content, but at lesser moisture content considerable beam strength was developed. Compressive strength behaved in much the same way.

In Figure 5 you will note the rates at which beam specimens dried out in the laboratory air and also the rate at which they absorbed moisture when placed in a saturated atmosphere. You will also note the difference in the absorption rates between plain specimen A and those containing either sodium or calcium chloride. It occurs to me that there may be some occasions when the use of the salts would tend to raise the moisture content so high that some of the strength would be dissipated.

We have experimented with methods for measuring capilarity and permeability of compacting mixtures. We have also started periodic sampling of existing stabilized road surfaces to determine the moisture content and performance. In some of the samples we have found surprisingly low moisture content in the base mixture, though the soil immediately below contained quite a high moisture content. These tests have not extended over the entire year's range of weather.

All these quests for knowledge along various lines will eventually produce new facts and new methods of control in construction, but in spite of all our efforts at the dissemination of information gleaned from our investigations we will probably always continue to **know different stuff.**

Formulas for Design of Bituminous Surfacing

Harger & Bonney Formula:

$$D=\sqrt{\frac{W}{3P}+\frac{T^2}{9}}-\frac{T}{3}$$

D—Depth of surfacing in inches.
W—Wheel load in pounds including impact.
P—Safe bearing value of soil in pounds per square inch.

Professor Downs' formula:

$$D=0.564\sqrt{\frac{W}{P}}$$

Bernard Grey's formula:

$$D=0.564\sqrt{\frac{W}{P}}-e$$

IOWA STATE HIGHWAY COMMISSION
Department of Materials and Tests
Test Report—Miscellaneous Materials
Laboratory—Ames

Material—Soil (Pit Run Lab. No. AAD6—6
Location—Templeton Pit, Ames, Iowa.

Sieve Opening M.M.	Sieve No. (U. S. Std. Series)	Per Cent Passing
25.40	1 in.	100.0
18.90	¾ in.	97.9
12.70	½ in.	95.2
4.76	No. 4	81.2
2.36	No. 8	70.5
2.00	No. 10	68.1
0.420	No. 40	33.2
0.295	No. 50	19.9
0.147	No. 100	7.0
0.074	No. 200	5.7
0.050	No. 270	5.0
0.005	....	2.0
0.001	....	0.3

Liquid limit, Plastic limit, Plasticity index—Unable to determine.
Per cent Shale in whole sample..........0.9%
Per cent Clay Lumps in whole sample..........None

IOWA STATE HIGHWAY COMMISSION

Department of Materials and Tests

Test Report—Miscellaneous Materials

Laboratory—Ames

Material—Soil Lab. No. AAD5-380

Location—NE¼, SE¼, Sec. 22, Clayton Twp., Taylor County.

Soils Department classification: Subsoil of Shelby Loam. Geologically a Gumbotil, resulting from long continued weathering, without much erosion, of Kansas Glacial Till.

Sieve Analysis

Sieve Opening M.M.	Sieve No. (U. S. Std. Series)	Per Cent Passing
2.00	10	99.9
0.420	40	95.6
0.295	50	93.6
0.147	100	88.1
0.074	200	85.7
0.050	270	83.9
0.005	......	27.8
0.001	......	12.4

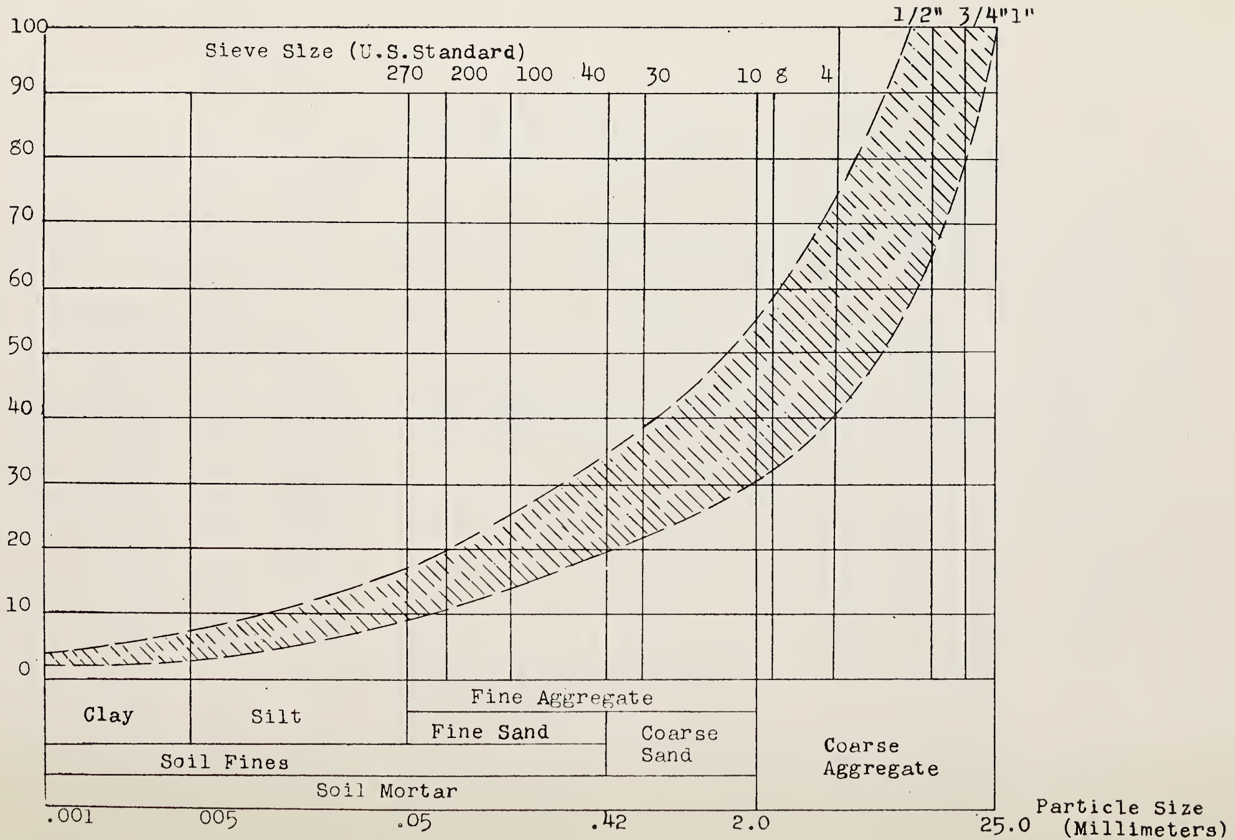
Liquid limit	42.8
Plastic limit	16.1
Plasticity index	26.7
Per cent Shale in whole sample	None
Per cent Material passing No. 8 (Tyler Std. screen scale)	100.0
Field moisture equivalent	26.1
Lineal shrinkage, per cent	6.8

COMPOSITION OF SOIL AGGREGATE MIXTURE TESTED

Parts Soil Per 100 Parts Gravel Sieve Size	15 Per Cent Passing	20 Per Cent Passing
4	100	100
10	86	87
40	49	57
100	20	23
200	18	21
270	17	20
.05	6	7
.001	2	2.5
Liquid Limit	19	20.4
Plastic Limit	10.8	9.6
Plastic Index	8.2	10.8
Field Moisture Equivalent	12.8	12.5
Lineal Shrinkage	1.3	1.8
Basic Proportions	1 part gravel 0.15 parts soil 0.128 parts water	1 part gravel 0.2 parts soil 0.113 parts water

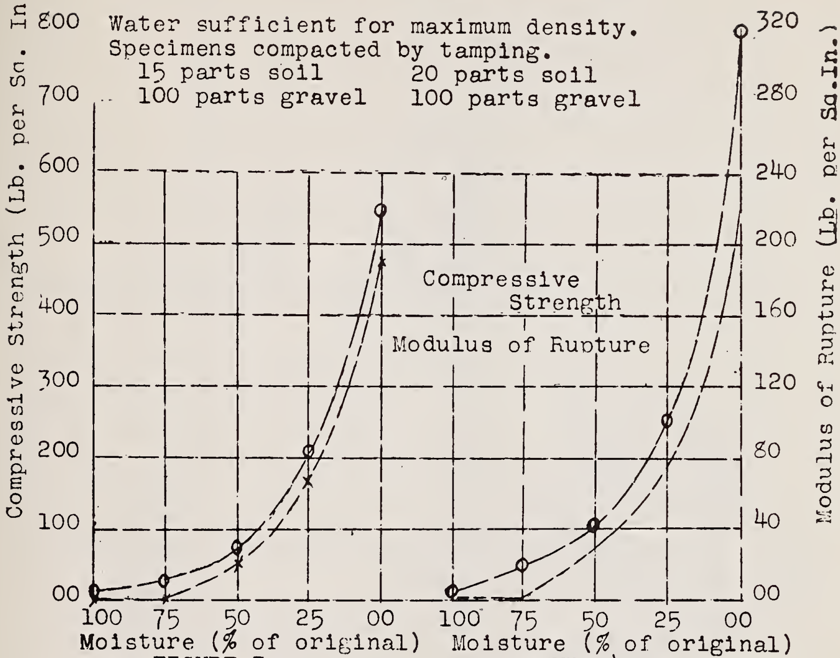
Only the material passing the 4 mesh sieve was used from the gravel.

Gravel represented by sample AAD6-6
Soil represented by sample AAD5-380


1/2" 3/4" 1"
Sieve Size (U.S.Standard)
270
200
100
40
30
10
8
4
100
90
80
70
60
50
40
30
20
10
0
Fine Aggregate
Clay
Silt
Fine Sand
Coarse Sand
Coarse Aggregate
Soil Fines
Soil Mortar
.001
005
.05
.42
2.0
25.0
Particle Size (Millimeters)

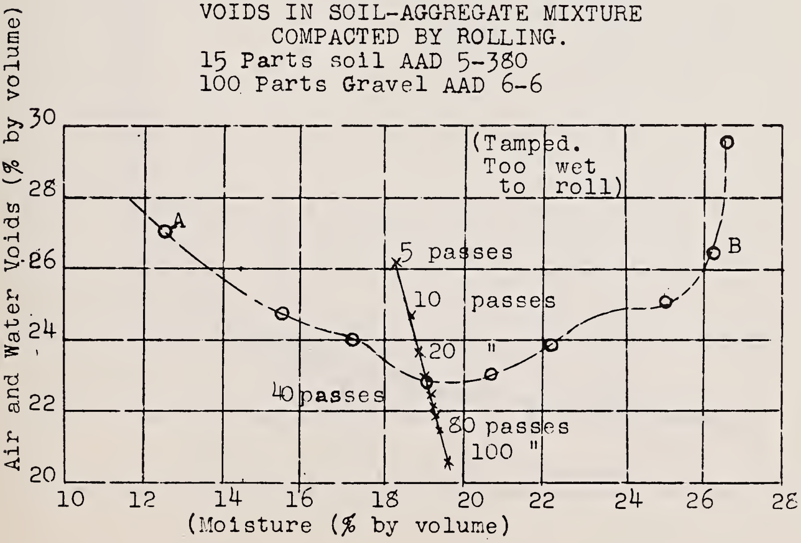
FIGURES 2-3-4

STRENGTH OF SOIL - AGGREGATE MIXTURES:



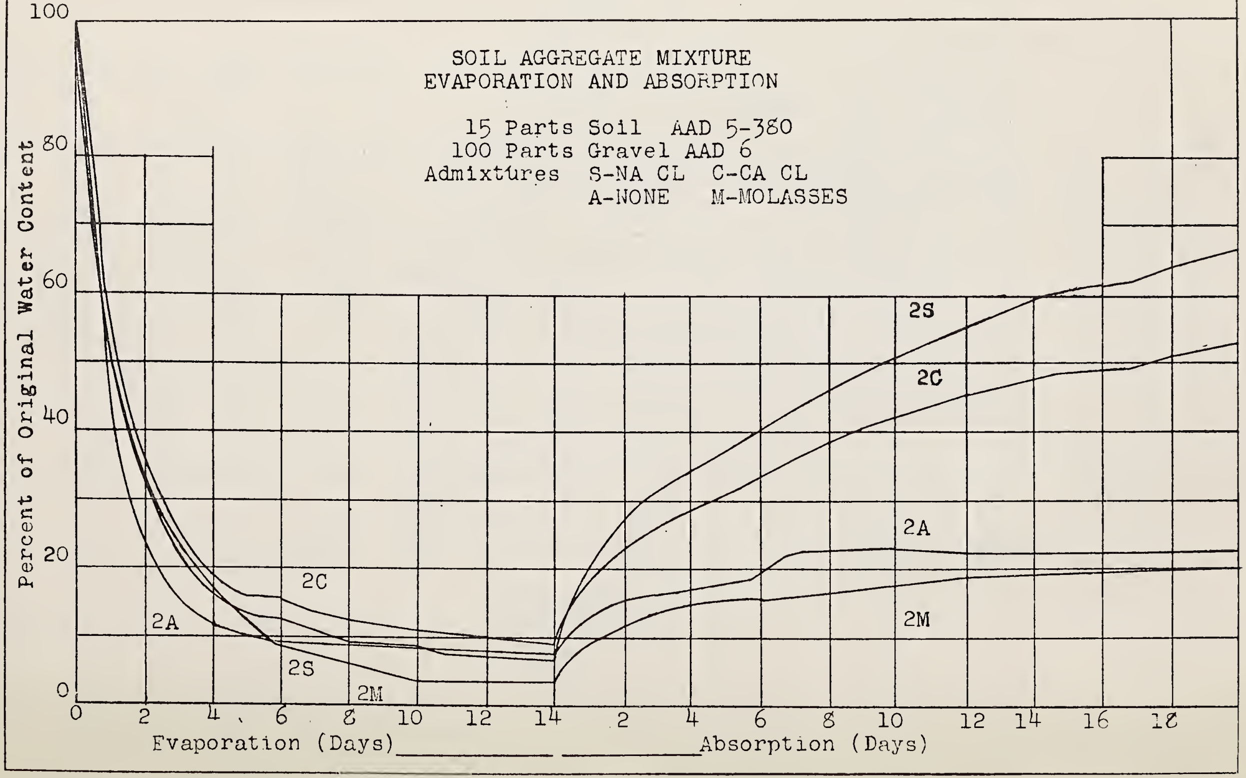
Water sufficient for maximum density.
Specimens compacted by tamping.
15 parts soil 100 parts gravel
20 parts soil 100 parts gravel

FIGURE 3 FIGURE 4



VOIDS IN SOIL-AGGREGATE MIXTURE
COMPACTED BY ROLLING.
15 Parts soil AAD 5-380
100 Parts Gravel AAD 6-6

Figure 5


SOIL AGGREGATE MIXTURE
EVAPORATION AND ABSORPTION
15 Parts Soil AAD 5-380
100 Parts Gravel AAD 6
Admixtures S-NA CL C-CA CL
A-NONE M-MOLASSES
Percent of Original Water Content
100
80
60
40
20
0
0
2
4
6
8
10
12
14
2
4
6
8
10
12
14
16
18
Evaporation (Days)
Absorption (Days)
2A
2C
2S
2M
2S
2C
2A
2M

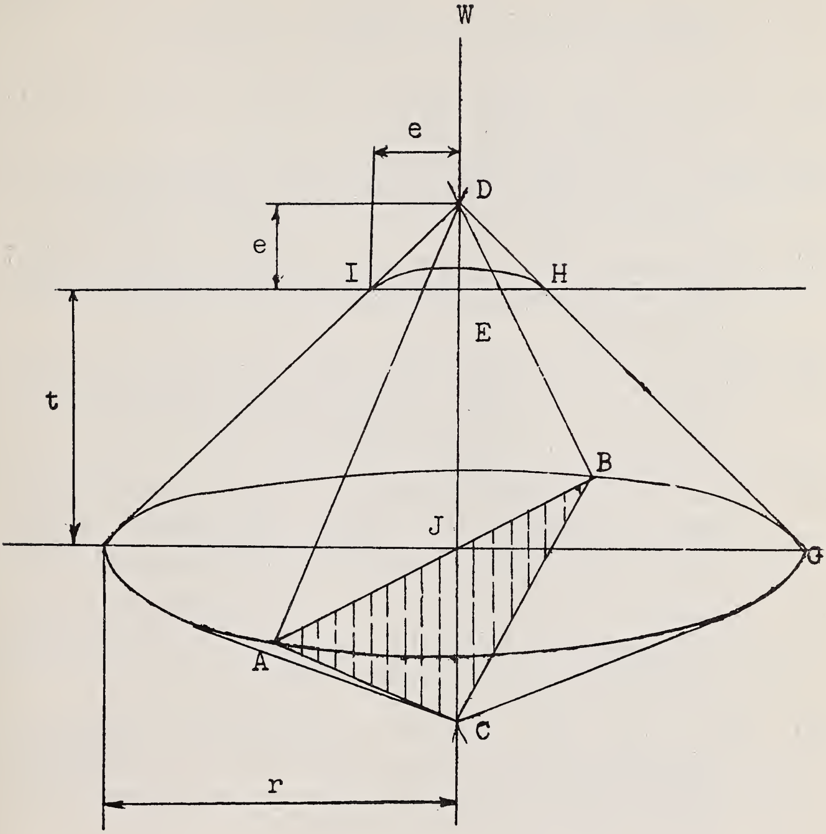


Diagram of Load Distribution
Thru Flexible Road Surfaces.

W = Wheel Load
JC = Max. Allowable Unit Subgrade Pressure
S = Total Subgrade Pressure = W
= Volume of Cone with base FAGB
and Apex at C.

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PREPARATION OF NATURAL SOILS FOR BITUMINOUS SURFACES

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INTRODUCTION

For any type of road there exists a definite relation between the condition of the subgrade and the efficiency of the surface of the road. This is true whether the surface is laid directly upon the natural soil or upon some type of special soil treatment or base course. It is especially true when semi-rigid type surfaces are laid directly upon the natural soil. Therefore, the primary problem in the construction of a bituminous road is the preparation of a satisfactory subgrade.

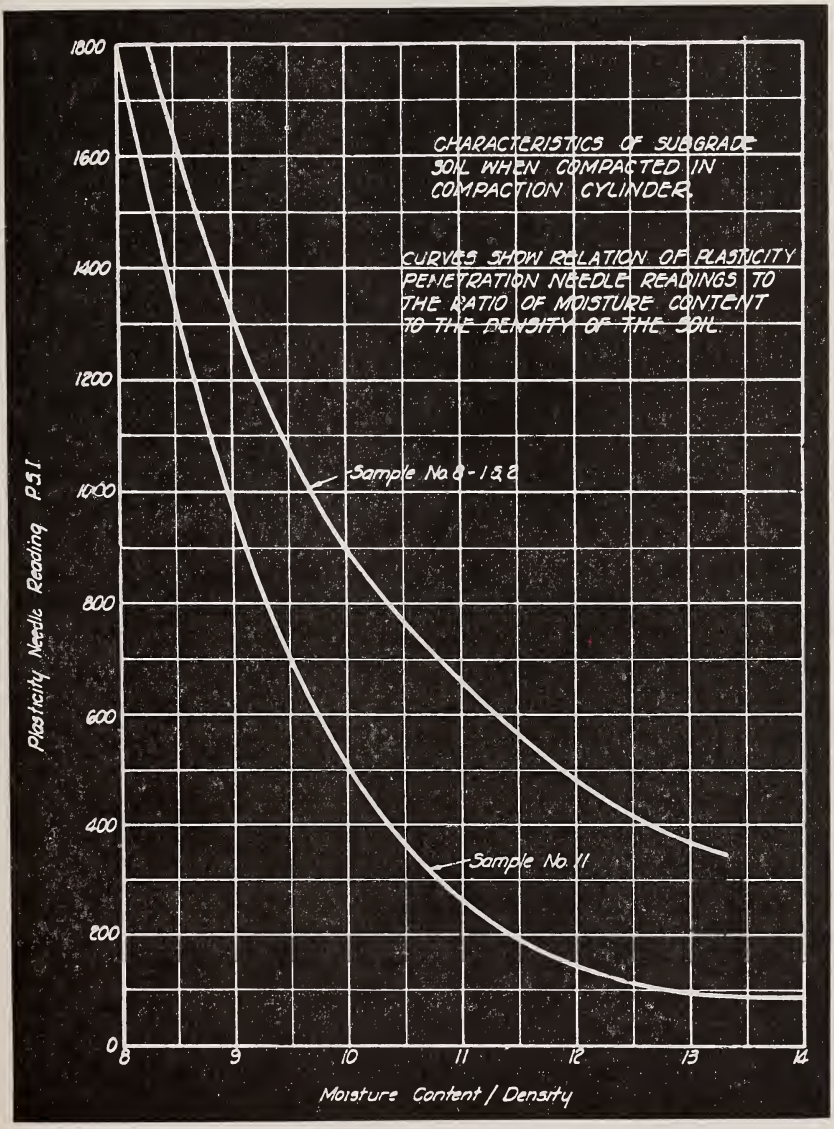
Generally speaking it is desired that each component part of a road is so constructed that it has: **ample bearing capacity** to carry the loads intended for it; **permanence** or resistance to change; and, that these conditions are **uniform** from cut to fill section throughout the length of the roadway.

The primary requirement for a satisfactory subgrade is that the subgrade have ample bearing capacity. Until Proctor did his work, no simple accurate method of obtaining bearing capacity had yet been developed by which bearing capacity could be translated into actual values of soil density and moisture content for any given soil. Kansas has done considerable work with the Proctor plasticity needle to determine the relations which existed between plasticity (or bearing capacity) and actual road conditions. Also to establish the relation between bearing capacity and moisture, soil density and other soil characteristics. These studies were limited to detailed tests on three projects, or approximately twenty (20) miles of bituminous surface. On these projects were found failures of almost every type which have been encountered.

The tests were conducted on a section of Highway U. S. 54 which traverses the oil fields of Southeastern Kansas. The traffic census showed a traffic count of 1250 vehicles per day, a considerable portion of which were heavy trucks, many of which approached the maximum legal wheel load of 10,000 pounds.

The results of these studies showed a definite relation between the Proctor needle reading and the stability of the subgrade. They also demonstrated that a relationship existed between moisture content, density, and stability of the subgrade and showed how these values differed for different soils. No failures were found where the needle readings of the subgrade exceeded 800 pounds per square inch. A few stable spots were found where the readings were as low as 600 pounds per square inch, but it was ob-

Requirements for Good Subgrades



(Figure No. 1)

served, in taking readings and making density and moisture determinations, that the thickness of the more dense surface layer was greater than at other points where a similar reading occurred at a point of failure. Thus the relation of the condition of the surface was not limited to the plasticity needle reading alone, but also to the depth of soil through which the reading was effective.

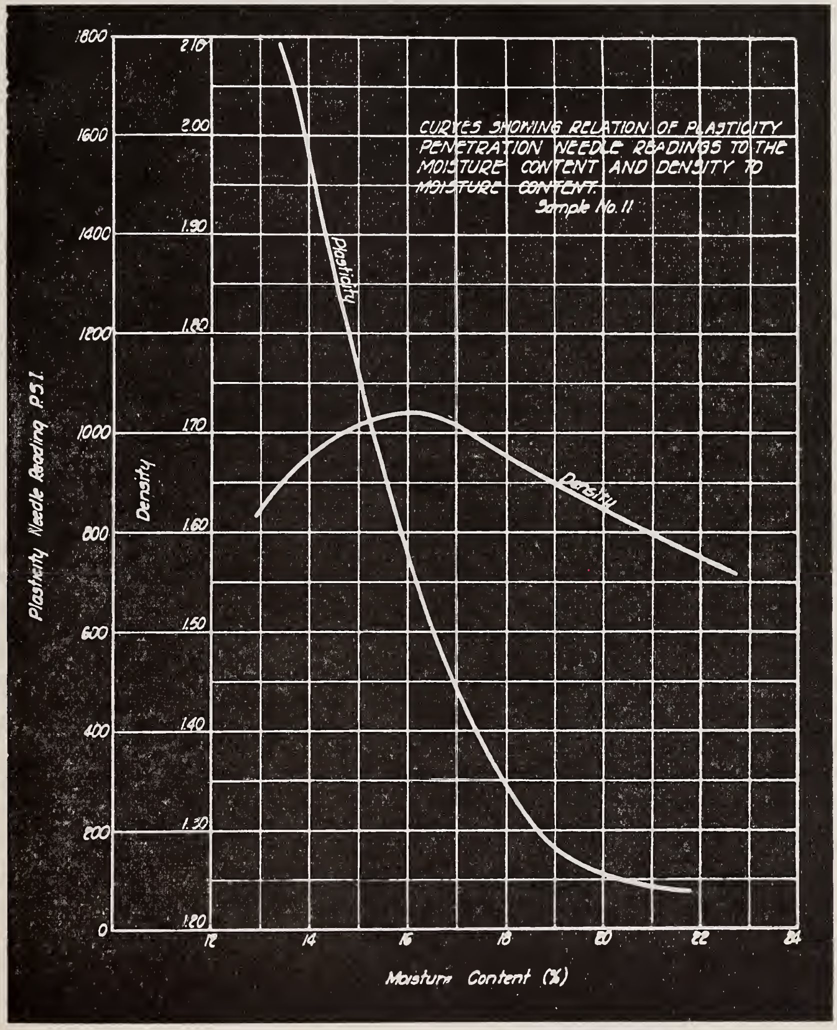
Further studies showed that the needle reading and moisture-content density determinations bore a direct relationship to each other. The relation between these values is obtained by plotting a curve of needle readings against the ratio of moisture content to density for the various conditions at which needle readings were observed. From these values it is possible to determine for each soil the maximum moisture content and minimum density values at which a particular soil will furnish ample bearing capacity as a subgrade for bituminous surfaces. On some soils it is difficult to obtain these conditions. However, a majority of soils may be compacted to meet the requirements of bearing capacity for bituminous surfaces.

The second requirement for a good subgrade is durability or permanence of the proper condition once it is obtained. There is no single condition of moisture content and density at which a soil will remain permanently. There is, however, a condition of moisture content and density at which a given soil offers the greatest resistance to change, that is, to either increase or decrease in moisture content, resulting in loss of stability. All changes—settlement, softening, shrinkage, swell, frost heave, etc.—result directly from change in moisture content and changes in temperature. The mere fact that a soil is compacted to its most durable condition does not mean that it is immune from change, but it does mean that it will, if given the best of protection, remain in a stable condition for a longer period of time.

The results of a large number of tests have shown that the most durable or most permanent condition, as it is related to subgrades for bituminous surfaces, is the maximum density obtainable with heavy duty sheepsfoot rollers with the soil voids at that density filled with water.

Soils having moisture contents during compaction sufficient to result in a condition of maximum density with the pore spaces as nearly as possible filled with water, after compaction offer greater resistance to the gain of moisture by absorption or the loss of moisture by evaporation than do soils compacted at any other condition.

The third requirement for any subgrade is that it be uniform and free from any decided variation in compaction, moisture content or condition which will result in roughness of the surface or occasional points of failure which serve as beginnings for failure over larger areas. The subgrade zone is by nature of soil occurrence and methods of construction apt to be non-uniform in character. The roadway itself is divided into two component parts, the embankment or fill section and the excavation or cut



(Figure No. 2)

section, the one differing considerably from the other. Between each of these sections, where the grade line intersects the ground line, is a section or zone of change from one to the other. In this zone there is usually a considerable change in soil type, moisture content, and state of compaction. (An example of the difference in density is shown in the accompanying figure.)

Only when conditions are made reasonably uniform from cut section to fill section can we expect to obtain uniform subgrade and surface conditions.

The extent to which each of the foregoing requirements can be obtained in a roadway depends largely upon the characteristics of the soils which are encountered and their location in the soil profile. Ample bearing capacity can be obtained on most soils, except on some members of the silt groups, the peats and the mucks. Except in localities where such soils are predominant, these unstable soils usually occur over such small areas that they can be removed and replaced with soils having the required stability. A major portion of the soils of the clay groups can satisfactorily be compacted so as to obtain values of bearing capacity sufficiently high for bituminous surfaces.

The case or difficulty of maintaining the desired conditions of moisture content and density of a soil is dependent to a very large extent upon the characteristics of the soil. Some soils are not subject to detrimental softening when they are allowed to become wet. These soils are of the A-1 group, the A-3 group and the more sandy, less plastic members of the A-2 group and some of the caliches and Mortar-bed-like materials which fall into the A-4 and A-5 groups. The latter soils become so thoroughly cemented under traffic that softening does not occur under the ordinary climatic conditions. There is considerable difference in the characteristics of soils of the clay groups. Some of the more silty clays, the organic clays, and some of the heavier structured waxy clays are very difficult to maintain as satisfactory subgrades. They are easily detected by inspection and testing. Many of the ordinary clays have been found to form very desirable subgrades and have given but little difficulty in being maintained in the desired condition.

Preparation of Soil—As a Natural Subgrade

(A) On New Construction

In Kansas we are attempting to so handle our new earthwork construction that only a minimum of preparation for later mat construction will be necessary. Soil surveys are conducted prior to the preparation of the plans. The soil survey includes mapping of the soil's profile and study of special soil conditions. Recommendations are then made to the Engineer of Design for special treatment or correction of conditions which experience has shown to be necessary or beneficial. Recommendations include such items as location of the most desirable borrow material, method of stabilizing sands, removal or special handling of unstable or undesirable soils, preparation of unstable embankment foundations, locations of drains to care for drainage of sub-surface water, treatment of points where the grade line intersects the ground line, placing of soils in the fill, etc. It has been found in Kansas that most locations can be improved as subgrades for bituminous mat by caring for such conditions as have been mentioned, without an unreasonable increase in the cost of construction.

Rolling of fills and tamping of the soil adjacent to structures is required on all principal traffic routes. In the eastern part of the state where the land is rolling or hilly, rolling and tamping is required even on the lighter traveled roads; on the lighter traveled roads of the flat plains where the amount of fill rarely exceeds two (2) feet, compaction is left to traffic except over the higher fills adjacent to culverts, bridges and over old channels. The latter, higher fills are in most instances rolled.

Compaction studies are made on all soils which are to be rolled. The Proctor mold is used in making the test. A hammer of new design, which eliminates, to a large extent, the personal element entering into the compaction of the soil, is being used in making the compaction tests.

The specifications for fill compactions are based entirely upon the results of the compaction tests. The specifications require the addition of water, when it is found by tests to be necessary, and special handling or allowing of materials to dry before they are placed in the fill when they carry excessive moisture, and cannot be compacted to meet the specifications. Tests are made to determine the density of the compacted soils to insure that specifications are being complied with.

Preparation of Soil—As a Natural Subgrade

(B) On Old Construction

Many of the older grades were jetted during construction. Others were constructed by casting and received no compaction during construction other than that furnished by the movement of the equipment over the grade as it was built. The subgrades of some of these older grades have become so unstable that tire loads have resulted in rutting and corrugating of the bituminous surface. On old grades where such conditions exist, the grade is torn loose, allowed to dry to the optimum moisture content, and re-rolled with a heavy duty sheepsfoot roller, in a similar manner and to meet similar requirements to those of new construction. The depth of the treatment depends upon the condition of the soil in the grade and may vary from six (6) to eighteen (18) inches below the surface. The operations have been carried on, both as regular maintenance jobs, and as reconstruction contract jobs. This type of reconditioning of the subgrade was begun only last year, therefore, it is not yet known just how much it will increase the life of the surface over that which was placed on the original grade. However, it is apparent that a much more uniform subgrade condition is obtained from this type of reconditioning than was obtained in the construction of the original grade.

Preparation of Soil—As a Subgrade for Base Courses

Base courses are constructed when traffic destroys the road surface because of failure of the natural subgrade soil to carry the loads. Base courses may be required over areas where the soil is naturally unstable, even when the soil is in a dry state, or over locations where special drainage conditions result in unstable subgrade conditions.

Regardless of conditions, the cost of constructing base courses is sufficiently high that there is little reason to purposely neglect the subgrade merely because a base course is to be constructed. Every precaution or care, in the preparation of the subgrade, which can be done economically, should be taken when a base course is constructed over the subgrade, just as when the natural soil is to act as the subgrade. Corrective treatments (which are discussed in following paragraphs) should be included where base courses are used just as they are where no base courses are used.

Corrective Treatments—Maintenance of Older Grades

(A) Drainage

Many of the older Kansas bituminous surfaces were originally constructed as surface penetration courses on sand-gravel surfaced roads. The bituminous penetration surface has been found to be an excellent, though not exactly a scientific means of detecting poor subsurface drainage.

Poor subsurface drainage has been found to result largely at planes of separation between rock ledges and the shale upon which it rests. Some seepage has been found in joint clays where the entire clay layer is waterbearing.

These conditions have been given a number of different types of drainage treatment. At some locations French drains have been constructed into a drainage system in the form of a chevron over the grade. This system of drainage consists of laterals placed at an angle of 45 degrees to the center line and meeting at the center line to form a "V." The laterals drain either directly into the side ditch or into parallel longitudinal drains placed in the shoulder or under the side ditch. This system of drain is used where it is difficult to locate a plane of seepage or where the road passes through a relatively thick water bearing stratum the bottom which is below the ditch line or where a number of seepage planes or strata are encountered in a relatively short distance. At other locations the drains have been laid parallel to and in the shoulder or below the ditch. Where the source of seepage was confined to a single plane, the drains have been laid in such a manner that they would intercept the water along the place of flow as it intersected the immediate subgrade. In other instances, perforated pipe and drain tile have been used to accomplish the same purpose of removing the subsurface water.

Where the soil was of an unstable nature through the zone of seepage, rolled crushed stone or sledge stone bases have been constructed. These bases have been built in such a manner that they would serve as drains and also furnish the necessary bearing support. Outlets have been provided to carry the water out into the ditches.

Recently, different methods have been used, leaving the old mat in place to act as an impermeable membrane, and the newly constructed base-course has been built directly upon the old existing bituminous surface. It was felt, in going ahead with this type of construction that where the failures were not of the most severe nature, that the added base would, with the aid of the old mat, sufficiently distribute the load that it would be unnecessary to remove the old mat, but rather to use it to the best advantage. The mats have been given some maintenance prior to this type of treatment in order to provide a smooth foundation for the base course. Sledged stone bases have likewise been built to care for the more serious type of failure due to lack of subsurface drainage. A major part of these bases have been constructed six (6) inches in depth.

One of the most successful methods of caring for locations which have failed because of lack of drainage, has been to leave the old mat in place, and cover it with approximately a one (1) foot depth of earth which is later surfaced with sand-gravel. The earth covered section is maintained as a sand-gravel surface until it has been completely consolidated by traffic. It is then given a bituminous penetration and later covered with a bituminous mat. Sections treated in this manner have successfully gone through one of the most severe winters on record and remain intact with no indication of failure going into their second year of service.

Surface drainage has, because of the extreme climatic conditions, become a more or less acute problem in Kansas. The extremely dry summers and severe winters (especially that of 1935-36) have brought about a situation for which we have yet no solution. Shoulders have developed cracks, during dry weather, which have been as much as an inch in width at the surface, and three feet or more in depth. As yet these cracks have been observed only in the shoulders and do not extend under the surface. Shrinkage cracks formed during last winter, however, were of a different nature. Some of them extended through the mat in both longitudinal and transverse directions. Subsequent thawing of the frozen ground did not entirely close the cracks. Water from the early spring rains entered the cracks and softened the subgrade causing failure of many miles of bituminous surface in the eastern part of the state. Just what percentage of the failures owe their origin to water entering shrinkage cracks is not known, but it most certainly is high, especially where the subgrades are of the clay and clay loam soils. A solution to this problem would materially lengthen the life of bituminous surfaces where these conditions exist.

(B) Treatment of Frost Boil and Frost Heave

The occurrence of frost boil and frost heave has been almost negligible in Kansas until the severe winter of 1935-36. Very little frost heave occurred, where surfaces were displaced to a noticeable degree. However, a number of frost boils, or places where, upon thawing, the soil completely lost stability, occurred at different localities throughout the state. They were as a rule small in extent, rarely exceeding two or three hundred (200-300) feet in length along the roadway. Many of them were small in extent, so small in fact, that the soft material was hand excavated and replaced with a porous crushed backfill. This backfill was connected to drains to remove additional water which might enter the zone of failure. Cement has been used in stabilizing a base course over some of the larger areas of failure of this type. In using the cement it was either mixed with the subsoil or the subsoil was removed to a depth of six (6) inches to one (1) foot and backfilled with selected materials to which cement was added. The cement was thoroughly mixed with the soil, then wetted and compacted in place. Each of the methods mentioned have been successful in keeping the surface intact to date. How these methods will react under another severe winter, is of course, unknown.

Preparation of Soils—The Use of Admixtures

It has been mentioned in previous paragraphs, that the stability of any natural soil is dependent upon two requisites: first, its natural stability when compacted during construction to the greatest density economically obtainable at the optimum moisture content, and second, the degree of permanence which can be maintained. When stability can neither be obtained nor maintained for a satisfactory length of time under good road construction and maintenance practice, it becomes necessary to provide both support and permanence by the construction of some type of base by improving the soil by the incorporation of some stabilizing admixture.

The action of the soils which constitute the subgrade is dependent so largely upon the soil moisture content that recently studies have been limited almost entirely to that of the nature or properties of that moisture. Two general types of stabilization have been developed—which attempt both to limit the amount of absorbed water and the effect which the absorbed water has upon the soil. They are briefly:

1. The addition of materials to the soil resulting in a mechanically stable mixture of proper grading, and supplementing this by incorporating chemicals to assist in maintaining the stability obtained.
2. The providing of binders, insoluble in water, to increase the stability of fine grained or poorly graded soils.

It has been mentioned that soils of the A-1, A-3 and some soils of the A-2 group retain stability to a considerable extent even though they have absorbed water. It has been found, by Dr. Winterkorn and others, that the extent to which even well graded soils remain stable depends partially upon the chemical nature of its constituents. In other words, the nature of the soil particles and the nature of their electric charges or ionization determines to some degree their affinity for water. This has led to the use of chemicals having electrolytic properties such as calcium chloride, common salt, sodium hyposulphite and a number of others to reduce the thickness of the water films which surround the particles and thus give the mixture greater density and correspondingly greater strength.

In the second type, the addition of admixtures is for the purpose of replacing as far as possible the water in the soil with a binder which is insoluble in water. Bituminous and Portland cement admixtures fall into this group. In the use of bituminous materials, either asphaltic oils, asphalts or emulsions, it is intended to surround each particle with very thin films of oil more substantial than those of water and thus destroy the colloidal properties of the soil. Cement, although acting in a slightly different manner, has been found to destroy the colloidal properties of soils and render them resistant to the action of softening due to the absorption of water.

Granular Admixtures

Gravel and sand admixtures with clay subgrades and clay admixtures with sand subgrades have been used over such a long period of time and have been subject to so much discussion that they need be given no further mention in this paper. In Kansas a considerable number of subgrades for bituminous surfaces have been improved by scarifying the subgrade, mixing the existing mat materials and added aggregates with the scarified subgrade soil and rolling the mixture back into place and covering it with a new bituminous surface.

Bituminous Treatments

Bituminous admixtures to natural soil subgrades have been constructed in a number of different types. Missouri has constructed a considerable mileage of surface penetration treatment. The type of construction, costs, use of primes and effectiveness of this type of treatment was discussed by Mr. Reagel of the

Missouri Highway Department at the 1935 meeting of this conference. Missouri has also constructed a short mileage of bituminous treatments of the Ingles or subterranean type as well as of the earth-asphalt-mixed in place type. The latter was mixed with the pugmill type of traveling plant. The Ingles type, which consists of depositing oil at the bottom of a four or five inch scarified layer, as well as the pugmill type mix were also described by Mr. Reagel at last year's conference.

The bituminous materials added included slow curing and medium curing oils, medium curing oils emulsified and commercial emulsions. Various quantities of aggregates were also added to some portions of the experimental sections of the road.

Both of the methods have been successful as a means of stabilizing the subgrade. However, they have not been entirely successful as surfaces, due to the fact that they do not successfully resist abrasion. Both types of mix require some type of wearing course if they are to be used to the best advantage.

It is reported that since the preliminary work was done the sub-oiling machine has been greatly improved with a more accurately controlled method for introducing the oil and a more satisfactory shoe for dispersing the oil.

Bituminous emulsions have had rather widespread use in a number of states, but have not yet been used as admixtures for stabilization work in Kansas. Emulsions have been used as admixtures in stabilizing airport runways and streets, as well as subgrades for highways. All types of soils can be stabilized by the use of emulsions. Like other bituminous treatments, however, the cost increases in proportion to the clay content of the soils. Where inexpensive sands, crusher waste or similar materials are available, the cost of stabilizing by the use of emulsions can be reduced considerably.

Considerable work has been done to introduce scientific methods for determining the proper mix to be used in constructing emulsion admixtures, as well as for making tests to determine the effectiveness of the various mixes towards stabilizing the soils. A modified form of the Hubbard-Fields stability test apparatus has been used to determine values of stability. Wet clay soils which have been found to have stability values as low as 15 pounds per square inch when tested with this apparatus, have been stabilized so that even after they had been allowed to absorb water the stabilized material has had a stability in excess of 3000 pounds per square inch when tested in a similar manner. Ordinary clay soils can be stabilized by using approximately one (1) gallon of 55% emulsified asphalt per square yard per inch of depth. By adding two (2) parts of aggregate to one (1) part of clay the amount of emulsion required is reduced to approximately one-third gallon per square yard per inch of depth. Commercial "stabilizer" emulsions have been prepared, which are much more effective both in reducing absorption and in maintaining increased stabilty after the mixture has been allowed to absorb water, than are the regular commercial coarse aggregate mixing emulsions.

Portland cement has been used effectively as an admixture in stabilizing soils in South Carolina. The process of stabilizing with cement consists of pulverizing the subgrade soil to the necessary depth, adding cement and thoroughly dry mixing it, then watering and compacting the mixture at the desired moisture content to the maximum density. To obtain a certain degree of hardening, the amount of cement may vary from 2 to 10 per cent, depending upon the properties of the soil being stabilized. As with some other materials, the cost, and difficulties of construction increase with increase of the clay fraction in the soil. The present information is that cement has possibilities as an admixture for stabilizing the "lighter" soils, that is, the sand, sandy loams, silts and silt loams which are not difficult to pulverize.

All of the different methods of admixture have not been constructed for a sufficiently long time to compare their relative merits. Neither have they been constructed of sufficient mileage to allow conclusions as to costs. Each has been found to be lacking somewhat in resistance to the abrasive action of traffic and therefore must be covered with a wearing course.

Each of the types has been found more effective and economical in the light soils. Asphalts and emulsions, especially the latter, have been found effective though somewhat more costly on the heavier clays.

None of the admixtures—except those of the granular type first mentioned, have been constructed in Kansas—with the exception of cement which was used in experimental studies to determine the effect of a cement admixture to reduce the swelling properties of subgrade under concrete pavements. Information covering the other types has been gained from discussions and from the publications which are available on the subject.

Summary and Conclusions

The economy with which subgrades for bituminous mats are prepared depends upon the **nature** of the soils, the **care** with which they are placed and the **protection** they are given toward maintaining the desired conditions. Climatic conditions play a large part and are often the deciding factor as to whether or not admixtures must be used or bases constructed to increase the supporting value of the soil. Lack of adequate drainage for both surface and subsurface, often make it appear that special bases of stabilization are required, when in reality, the failures occur only at those places where proper drainage is lacking. When it is apparent that stabilization is necessary, considerable thought should be given toward which type of admixtures will best fit the particular soil conditions—or whether it would be more economical to construct a base course.

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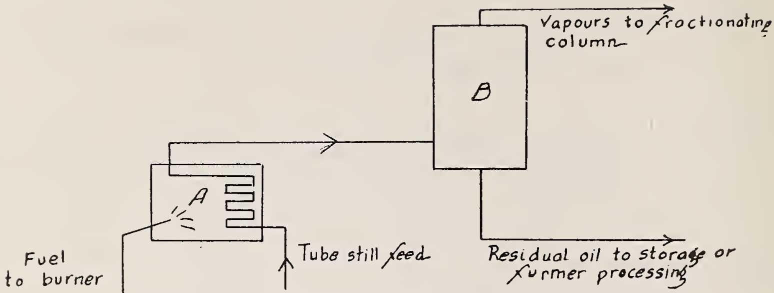
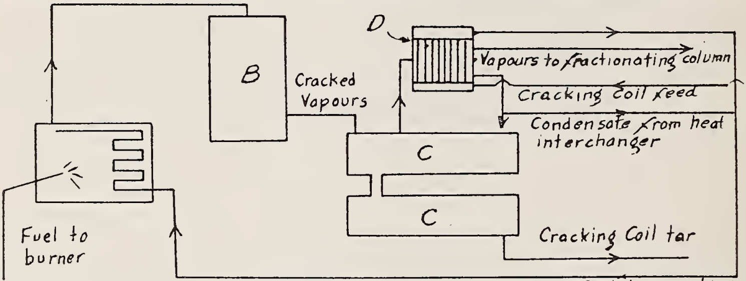
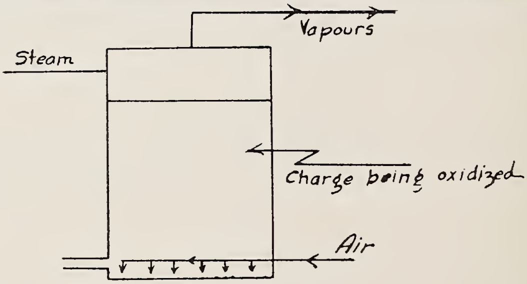

Vapours to fractionating column
B
A
Fuel to burner
Tube still feed
Residual oil to storage or further processing

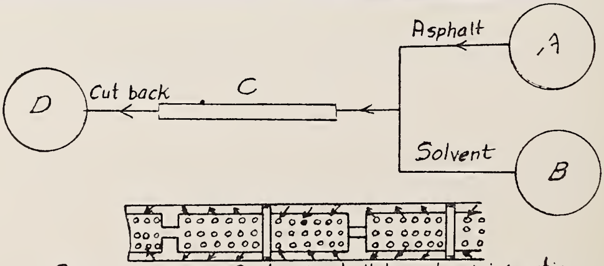
Tube Still or Flash Coil
FIG 1


D
B
Cracked Vapours
Vapours to fractionating column
Cracking coil feed
Condensate from heat interchanger
C
C
Fuel to burner
Cracking Coil tar
Hot feed to cracking coil

Cracking Process
FIG. 2



Oxidation Process
FIG. 3.



Section of mixer C showing bullets and mixing action

Manufacture of Cut backs FIG. 4.

CHARACTERISTICS OF ASPHALTIC MATERIALS

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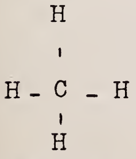
Chemical Composition

All bituminous materials are composed of organic compounds largely hydrocarbons in composition. Since the chemical and physical properties of all compounds vary with their molecular structure, the first few paragraphs below contain a very brief description of the elementary structure of the principal groups of hydrocarbon materials, and the types of structure most susceptible to change by chemical means.

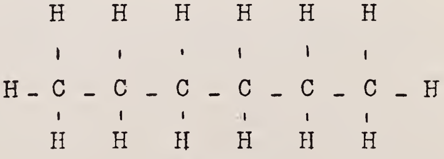
Because of the enormous variety of structure observed in organic compounds, no simple classification of these materials is very well justified. In general, however, organic compounds are considered to be divided into two major divisions (1) aliphatic compounds, (2) aromatic compounds, to which a third division, naphthenic compounds, should possibly be added.

Aliphatic compounds may be considered to have been derived from methane, and possess an open chain structure. From one to sixty or more carbon atoms are linked together in a chain, with hydrogen, oxygen, or other atoms attached to the carbon atoms. Methane, a gas, and hexane, a liquid, may be considered to generally illustrate the structure of this series of compounds.



$$\begin{array}{ccccc} & & H & & \\ & & | & & \\ H & - & C & - & H \\ & & | & & \\ & & H & & \end{array}$$

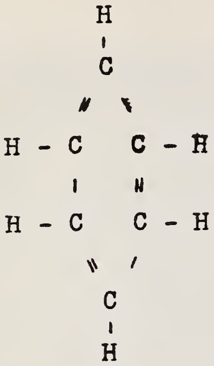
Methane



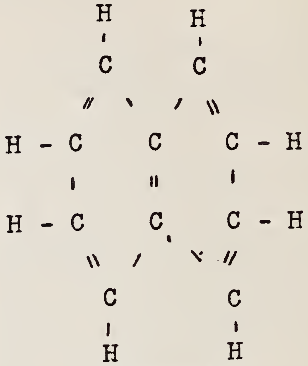
$$\begin{array}{ccccccccccccc} & & H & & H & & H & & H & & H & & H & & \\ & & | & & | & & | & & | & & | & & | & & \\ H & - & C & - & C & - & C & - & C & - & C & - & C & - & H \\ & & | & & | & & | & & | & & | & & | & & \\ & & H & & H & & H & & H & & H & & H & & \end{array}$$

Hexane

Aromatic compounds consist of benzene and derivatives of benzene. In structure, they are closed chain or ring compounds in which two valences are used to join alternate pairs of carbon atoms to each other. Examples of aromatic compounds are benzene, a liquid, and naphthalene (a polybenzene), a solid.



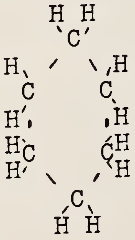
Benzene



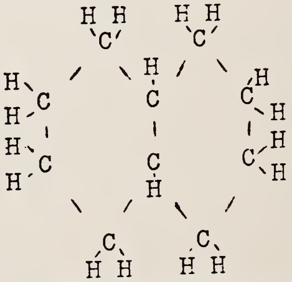
Naphthalene

As may be surmised from their name, many aromatic compounds have fragrant odors, but this is not necessarily true.

The naphthenic series of hyrdocarbons resemble the aromatic compounds in possessing a closed chain or ring structure, but behave chemically more like the aliphatic compounds. Cyclohexane, a liquid, is the standard example of a naphthene hydrocarbon, the polynaphthene, decahydronaphthalene, also a liquid, is another.



Cyclohexane

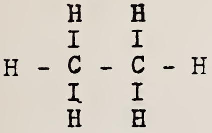


Decahydronaphthalene

The carbon atom possesses four valences, or bonds, each of which must be attached to another atom, and if other species of atoms are not available, the valences of the carbon atoms join to each other. If only one valence is used for each carbon to carbon linkage in a compound, the compound is said to be saturated, and if two or more valences are used between two carbon atoms the compound is said to be unsaturated. Unsaturated compounds are very reactive chemically.

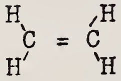
Two or more unsaturated molecules may combine with each other to eliminate one or more of the double bonds and form a larger and more chemically stable molecule. The gradual formation of gums in poorly refined, cracked, gasoline during storage, is considered to be due to the combination of a number of small unsaturated molecules, forming the much larger gum molecule. The combination of two or more molecules to form a larger molecule is called polymerization.

Ethane is a saturated hydrocarbon, ethylene and acetylene are unsaturated.



$$\begin{array}{ccccc} & H & & H & \\ & | & & | & \\ H - & C & - & C & - H \\ & | & & | & \\ & H & & H & \end{array}$$

Ethane



Ethylene

$H - C \equiv C - H$

Acetylene

Ethylene is more reactive than ethane, and acetylene is more reactive than ethylene, forming explosive compounds even with air.

The aromatic compounds differ from the napthene compounds due to the presence of double bonds between alternate pairs of C atoms in the benzene ring, which is not true of the structure of the naphthenes.

It is quite possible and quite common for any combination of aliphatic, naphthenic, and aromatic hydrocarbon groups to appear together in the same molecule, and one group may be changed chemically without effecting the others by suitably controlling the reaction environment. The presence of double or triple bonds between carbon atoms in any group in the molecule, renders that portion of the molecule particularly susceptible to chemical attack. Due to the very large number of ways in which members of the three groups can combine, it can be easily understood that organic compounds may become quite complex, particularly when other elements like oxygen, nitrogen, sulphur, etc., may replace some of the carbon or hydrogen atoms in some molecules.

The chemistry of the aliphatic and aromatic hydrocarbons has been fairlly well investigated, but to date very little work has been done on the naphthene compounds.

Almost every crude petroleum contains at least a small percentage of representatives of each of these three major groups of organic chemistry.

It is believed that the hydrocarbons generally present in most lubricating oils, and a very considerable proportion of the hydrocarbons present in asphalts and asphaltic oils belong to the naphthene series.

As to the actual chemical compounds present in asphalts and asphaltic oils, almost nothing is known.

The various compounds present in asphalts have been divided into five principal groups by Marcusson, on the basis of the chemical and physical properties of each group. Marcusson's five principal groups are (1) oily constituents; (2) asphaltic resins; (3) asphaltenes; (4) carbenes; (5) asphaltic acids and their anrydrides. A brief description of each as follows:

Oily Constituents

These have the appearance of a clear, viscous, reddish-brown colored lubricating oil. They contain small percentages of oxygen and sulphur. They are separated from an asphalt by mixing it with fuller's earth, when all groups but the oil constituents are adsorbed, and extracting the mixture with petroleum ether. They are the most inert fraction of an asphalt.

Asphaltic Resins

The asphaltic resins are reddish to dark brown solids having a softening point of 200 degrees F. or higher. When adsorbed by clay they become insoluble in petroleum ether due to polymorization largely to asphaltenes. They result from the oxidation of the oily constitutents. They form true solutions with some solvents.

Asphaltenes

Asphaltenes appear as a brown to black powder which does not melt on heating but swells. They are formed from the resins by further oxidation with sulphur or exygen, and when dissolved form colloidal solutions. They are insoluble in petroleum ether, but are soluble in carbon disulphie and carbon tetrachloride.

Carbenes

These are present in bituminous oils only to the extent of a fraction of one per cent usually. They appear as a brown to black powder soluble in carbon disulphide but insoluble in carbon tetrachloride. They seem to be polymerization products of the asphaltenes.

Carbenes, like the resins and asphaltenes, are considered to be polycyclic in structure containing oxygen and sulphur in bridge and hetcrocylic linkage.

Asphaltic Acids and Their Anhydrides

These can be removed from an asphalt by water washing after refluxing with alcoholic potash solution. The solution of their alkali metal salts is clear and dark brown in color. At high temperatures they are transformed to unsaponifiable substances which likely explains their low concentration in petroleum as compared with natural asphalts.

The structure, and physical and chemical properties of these various groups, vary with the crude, and with the method of refining or manufacture. These differences in the structure, and in the physical and chemical properties of the constituents, are reflected in the differences in the characteristics of asphalts obtained from different sources.

The Colloidal Structure of Asphalts

Nellensteyn[1] describes asphalts as a colloidal system consisting of a suspension of asphaltenes in a viscous, liquid, medium.

The liquid medium consists of the oily constituents and likely includes some dissolved resins.

Each asphaltene particle Nellensteyn believes to consist of a nucleus of a solid carbon or mineral particle, so small as to be visible only in the ultramicroscope, surrounded by an atmosphere or shell of asphaltic resins which are held to the surface of the solid particle by adsorptive forces.

According to Nellensteyn's view, then, the asphaltene fraction of the asphalt consists of what Marcusson calls asphaltenes, plus part or all of what Marcusson has called asphaltic resins.

This is scarcely in accord with the physical and chemical properties of these two materials as given by Marcusson, nor is the resistance of the adsorbed resins to leaching with paraffin naphtha, in which the resins are soluble, in the determination of percentage of asphaltenes, in accord with the generally understood behavior of adsorbed materials.

Nellensteyn further suggests that the adsorbed resins are dissociated and adsorbed as ions, which would explain their ability to withstand leaching with paraffin naphtha, but this means that the absorbed resins are present as free radicals. This view does not seem reasonable since free radicles are very reactive chemically, and asphalts are relatively quite inert materials.

It is generally accepted that asphalts are a colloid system, and possibly the most rational view on the basis of present knowledge concerning them is that expressed by Mack[2].

He considers the asphaltenes and carbenes to be distinct entities dispersed in a medium consisting of a solution of asphaltic resins in the oily constituents. A part of the resins is adsorbed by the asphaltenes and carbenes by secondary valence forces, where they possibly function as a protective colloid, but they are dissoved when the asphatenes are precipitated in petroleum ether.

The Origin of Asphaltic Materials

There is a wide difference of opinion as to the origin of the natural asphaltic bodies in crude petroleum.

It is considered by some that the mother substance of the crude petroleum in the earth today, evolved paraffinaceous or asphaltic crudes in any locality, depending on the temperature, pressure, and time.

Because it is possible to change paraffinaceous residues into asphaltic materials with high temperature and pressure, some consider that original paraffinaceous crudes may have been made asphaltic by the effects of lower temperature and pressure acting over long periods of time.

On the other hand, Brooks[3] states that paraffin is formed during the distillation of asphaltic oils by the decomposition of the asphaltic matter. Crystalline paraffin is found in shale oil which was not present in the original shale.

From asphaltic petroleum the various natural asphaltic materials are formed by the further action of temperature and pressure, and possibly by reaction with oxygen from the air, and with oxygen and sulphur in adjacent rock deposits.

The asphaltenes are polymerization or condensation products of the oily constituents and resins. This means that several molecules of the oily constituents and resins, or parts of these molecules, combine to form the larger and more complex asphaltene molecules. The asphaltenes in turn polymarize or condense to carbenes, which are still more complex in their molecular structure, and these in turn to carboids.

As the oily constituents and resins continue to be converted into asphaltenes and carbenes, the asphaltic material becomes harder.

Thus there are deposits like the Alberta tar sands where the bitumen has a softening point of 40 degrees to 90 degrees F., with an asphaltene content of 12%. Trinidad asphalt has a softening point of about 140 degrees F. with an asphaltene content of about 37%. Gilsonite has softening points ranging up to 400 degrees F. and an asphaltic content of as high as 80%. Grahamite has a softening point ranging to 625 degrees F. with a carbene content ranging to 80%.

Even grahamite can be further metamorphosed, and may finally become impsonite, possibly the ultimate in the metamorphosis of asphaltic petroleum. Impsonite however, contains no bitumen, if by bitumen is meant material soluble in carbon disulphide as set by the A. S. T. M., since the asphaltenes and carbenes in grahamite have been metamorphosed to carboids in impsonite, and these are insoluble in carbon disulphide. Impsonite is so hard that it cannot be softened by heat and is termed infusible.

Bituminous coal cannot be considered an asphaltic substance since it is composed of a large percentage of oxygenated compounds, and one distinguishing property of asphaltic substances is that they are substantially free from oxygenated bodies. The hydrocarbons present in bituminous coal are insoluble in carbon disulphide.

It is likely that all asphaltic materials have been liquids at some stage in their metamorphosis. Bituminous coal, however, is considered to represent a stage in the metamorphosis of some of the soild material in the vegetable matter from which our coal beds have come.

Petroleum asphalts are formed by the distillation of volatile matter from asphaltic crudes, by the oxidation of residues obtained by distilling any crude petroleum, and by the cracking of gas oil fractions, the residues from the distillation of petroleum, crude oils, or mixtures of these.

The Manufacture of Asphaltic Materials

(1) Petroleum Asphalts

The manufacture of petroleum asphalts has been very well outlined by Baskin[4], who gives a brief history of the various methods of manufacture, and a comprehensive discussion of the advantages and disadvantages of the various processes, with the effect of each process on the properties of the finished asphaltic material.

(a) The Shell Still

Asphalts were originally made by batch distillation as asphaltic crude in cylinderical stills of 1000 to 1500 barrels capacity. The crude was distilled by heat alone, or by applying heat and bubbling dry steam through the crude, until the residue had reached the required consistency. Due to the long time at high temperature in the stills, the asphalt residue was liable to be damaged.

(b) The Flash Coil

The tube still, or flash coil, was introduced because of its higher efficiency and the greater percentage of gasoline which could be recovered from a crude. The crude oil or other feed to the tube still, is at the maximum temperature for only a fraction of a minute, so that the residue is less liable to damage from overheating, or from being exposed to a high temperature for a long time.

Fig. 1 is a sketch of a flash coil, or tube still.

Crude oil or other feed, generally preheated, is pumped through a long coil of tubes set in a firebox A, where it is heated to 800 degrees F. or higher, under a pressure of 250 pounds per square inch or more. The hot oil passes into the flash chamber B, where there is a slight drop in temperature, and the pressure is reduced to 25 pounds per square inch or less, or a vacuum may be used. The oil separates to vapours which flash off, and a liquid residue. The vapours are drawn off the flash chamber and passed through one or more fractionating columns, and then through a condenser. The asphaltic or other residue is continuously drawn off the bottom of the flash chamber. Its consistency is controlled to some extent by the rate at which it is removed, and by the temperature and pressure of the feed just before it enters the flash chamber. Steam may be blown through it while in the flash chamber to drive off further volatile matter and shorten the time required for it to reach a desired consistency. The consistency which can be reached is limited however, by the necessity to draw off sufficient residue to keep the process continuous. If harder materials are required the asphaltic residue must be further processed in an asphalt coil, or steam reduced in a still to the consistency required.

(c) Cracking Process

Cracking processes were evolved from the desire of refiners to procure the maximum quantity of gasoline from any crude.

By these processes, hydrocarbons which would apear as heavy distillates and residues in the shell or tube still processes, can be converted very largely into gasoline by suitable control of temperature, pressure, and time, the only other products being gases, coke, and cracking coil tar (pressure tar), or just gases and coke if desired.

The term "cracking" means that under the influence of the high temperatures used, the hydrocarbon molecules in the feed to the cracking coil are split into fragments, and under the influence of the high pressures employed, these fragments of molecules combine to form molecules of gases, gasoline, cracking coil tar, and coke, as ultimate products. Some heavy distillates leave with the gasoline but these are returned with the feed to the cracking coil and are recracked.

The processes taking place in the cracking coil give a striking illstration of the working of the well known Le Chatelier's principle, which states that if a stress is applied to a system of equilibrium, the system will tend to rearrange itself in such a manner that the stress is relieved. When high temperatures are applied, the stress of temperature tends to be relieved by fragmentation of the molecules since this requires absorption of heat and tends to reduce the temperature applied to the system. The stress imposed by pressure tends to be relieved by the combination of some of the fragments into the complex molecules of asphalt, which are liquid at the temperature and pressure on the system, and tend to reduce the pressure by their condensation to the liquid state.

The use of high temperatures without pressure (destructive distillation), tends to produce materials which are largely gases at ordinary temperatures, whereas the use of high temperatures with high pressures can be made to give materials which are largely liquids at ordinary temperatures, and by recycling through the cracking coil, a very large portion of these liquids can finally be converted into gasoline.

The higher the pressure used, up to 1000 pounds per square inch at least, the more asphaltic is the cracking coil tar obtained.

The outstanding features of cracking coil asphalts are:

(1) Up to a certain point, the higher temperatures and pressures, and the longer the time element, used in their manufacture, the more asphaltic is the residue obtained.

(2) Cracking coil residues, when straight reduced, give solid and semi-solid asphalts of higher specific gravity, higher ductil-

ity, greater susceptibility to temperature change, and considerably lower consistencies than equivalent softening point, direct reduced, asphalts from crude petroleum.

(3) The cracking coil asphalts can be made fully as soluble in carbon disulphide as current asphalts from straight reduced crude, and are usually higher in asphaltene content.

There are a number of cracking processes widely used today, including Burton, Dubbs, Cross, Tube-and-Tank, etc., all of which naturally are different in details of the cracking process.

Fig. 2 is a sketch of one cracking process. The residue from the crude after the gasoline, kerosene, and gas oil fractions have been removed in stills,, is pumped through the high pressure heat interchanger D to the cracking coil in the firebox A, under a pressure of 50 pounds per square inch, where it is heated to a temperature of 875 degrees F. It passes into the soaking drum, or reaction chamber, B, still at the same pressure, where most of the fragmentation and some of the rearrangement of molecules takes place, some coke being deposited. The vapours pass into the separators C, also at the same pressure, where some further cracking occurs, the distillate and gases being removed from the top as vapours, while the cracking coil tar is removed from the bottom as a liquid.

The vapours are passed through the high pressure heat interchanger D on their way to fractionating columns, and give up some of their heat to the cracking coil feed. The high boiling fractions tend to condense in the heat interchanger and these may be returned to the separators C, or returned as feed to the cracking coil to be recracked.

The viscosity of the cracking coil tar is regulated by the rate at which it is drawn off from the separators, and by the amount of high boiling point fractions returned from the heat interchanger, the faster the rate at which it is withdrawn, and the larger the amount of condensate returned to the separator from the heat interchanger, the lower is the viscosity of the cracking coil tar withdrawn, and vice versa. Conditions can be so regulated that either S.C. 1, S.C. 2, or S.C. 3 can be drawn directly from the separators in their finished form. If a slower rate of withdrawal were maintained, and no condensate returned, to obtain asphaltic oils of higher viscosity, the material would accumulate in the separator and prevent continuous operation.

For this reason, if asphaltic materials of higher viscosity or consistency are required, the cracking coil tar is further reduced by passing it through an asphalt coil, or is placed in a shell still and steam reduced to the desired consistency.

An asphalt coil is essentially a flash coil, a sketch of which is shown in Figure 1. Cracking coil tar, or asphaltic residue from a tube or shell still is fed to the tube coil in the firebox A and heated to 750 degrees F. under atmospheric pressure. It enters the flash chamber where the pressure may be atmospheric or vacuum, and the more volatile matter present flashes off as vapour. The liquid residue in the bottom of the chamber is blown with steam to aid the escape of the oily vapours. Steam may also be added before and after the passage of the material through the coil, ahead of the flash chamber, to obtain more rapid reduction to the required consistency. The residue is withdrawn at such a rate that it has the consistency desired.

(d) Oxidation

In general, steam reduced, or stripped, residue oils from shell or pipe stills, and from cracking coils, do not have the low susceptibility to temperature changes, and the resistance to weathering possessed by oxidized asphalts of the same softening point and volatility[5]. Oxidizing these materials gives them the low susceptibility and weather resistance greatly desired for paving and roofing asphalts. The cheapest oxidizing agent is air, and asphalts are generally oxidized by blowing air through them at temperatures of about 450 degrees F.

Oxidation is chiefly a dehydrogenation process, for most of the oxygen therefore increases the carbon to hydrogen in an asphalt. The oily constituents are converted to resins, and the resins are converted to asphaltenes, by this process. When the hydrogen atoms are split off the moleclues of the oily constituents and resins by the oxygen of the air to form water, the remnants of the molecules are unsaturated, and these unsaturated residues condense (combine with each other) to form the more complex resins (from oily constituents) and asphaltenes (from resins).

Fig. 3 is a sketch of an oxidation process.

The preheated residual oil, after reduction by steam distillation or flash oil to the softening point or penetration at which it is desired to have oxidation begin, is fed into a still, usually vertical, in batches. Air is introduced through a series of perforated pipes at the bottom of the still and bubbles through the hot asphalt. The oxidizing process develops considerable heat and usually no external heat is required. By regulating the quantity of air introduced, the temperature of oxidation can be controlled within the desired range which is usually not higher than 550 degrees F. Steam is introduced into the vapour space in the top of the still to eliminate the possibility of an explosion of the air and oily vapours carried off. The oxidizing period may be from several to fifteen or twenty hours, depending on the nature of the charge, the product required, and the oxidation temperature. The oxidation is controlled by tests made on samples withdrawn from time to time.

By varying the amount of distillation and oxidation of a given crude oil, it is possible to produce asphalts of widely varying characteristics.

(d) Cut-back Asphalts

In order to secure the greater weather resisting properties, resistance to water action, and the greater stability imparted to bituminous mixtures by the use of semi-solid asphalts, and at the same time the workability without heating, given to mixtures by the use of low viscosity, non-volatile, bitumens, modern low cost bituminous practice tends toward the greater use of cut-back asphalts.

A cut-back asphalt is made by fluxing, or cutting back, a semi-solid asphalt with a suitable volatile solvent to specified viscosities, the consistency of the asphaltic base and the volatility of the solvent being so chosen, that the required specifications for the finished cut-back product can be met.

At the present time, bituminous practice has divided cut-back asphalts into two types, the medium curing (M. C.), and the rapid curing (R. C.) materials. The M. C. cutbacks contain a kerosene-type solvent, which evaporates slowly, while the R. C. cutbacks contain a gasoline-type solvent which evaporates rapidly.

The M. C. cut-backs are used as binder largely with dense graded aggregates for both road-mix and plant-mix, and as a primer. Their slow curing characteristics permit mixtures in which they are the binder to be manipulated for a considerable time after the addition of the cut-back, and the softer films of bitumen which are present for a considerable time about the particles, permit dense graded aggregates to become more thoroughly compacted in a shorter time than would be possible with the harder films of bitumen rapidly left by an R. C. cut-back, or with the hard films of bitumen given by a high viscosity or semi-solid S. C. material.

The R. C. cut-backs are used largely as binder for open graded aggregates, and for seal coating and other types of surface treatment.

Fig. 4 shows how cut-back asphalts are made. Asphalt of the proper consistency, and suitable solvent, are pumped in the proper proportions from the asphalt tank A, and the solvent tank B, through the mixer C, into the cut-back storage tank D. The mixer consists of a number of short perforated cylinders, called bullets, placed in a long cylinder of larger diameter. The mixer is so designed that the mixture of solvent and asphalt flows through the perforations in the bullets as it is forced through each bullet in turn. The construction is such that turbulent flow is produced which gives a good mixing action. If the mixture is not of a satisfactory homogeneity after passing through the mixer once, it can be pumped through again. If the viscosity is not right, more solvent or asphalt may be added as required while it is being recycled.

(e) Asphaltic Emulsions

Cutting asphalts back with solvents is one way of using hard asphalts in a liquid state without the application of heat. Dispersing these asphalts in water as an emulsion is another method.

Bituminous emulsions possess the advantage over cut-backs that they may be used with wet aggregates. When they are used as binder with dense graded aggregates, there has been considerable difficulty in the past with the emulsion breaking too soon during mixing operations. This detrimental feature is claimed to have been remedied recently.

It is not a difficult matter to disperse asphalt as minute globules in water. The principal problems involved in the preparation of bituminous emulsions centre around the stabilizing of these dispersions so that they do not coagulate on standing, and at the same time so regulating this stability that the emulsion breaks at the proper time when used. Thus for penetration and surface treatment types of construction, a relatively unstable, fast breaking, emulsion is required. For mixing with aggregate, the emulsion must be sufficiently stable that it does not break until all particles of the aggregate have been coated, and the mixture has been satisfactorily placed and finished on the road surface.

The substance added to stabilize dispersions of asphalts in water are called emulsifying agents. The stabilized condition is brought about by the large reduction of interfacial tension when a suitable emulsifying agent is adsorbed at the water-bitumen interface. Many substances have been patented for this purpose, but the substances most generally used are cheap soaps and finely divided clays. If the asphalt is sufficiently high in hydrocarbon acid substances, the addition of an alkali hydro-oxide will bring about an emulsion, the alkali forming a soap in situ at the interface between the bituminous globules and the water.

Bituminous emulsions generally consist of approximately 50% bituminous material and 50% water. The emulsifying agent usually amounts to from 1% to 2% of the emulsion.

The emulsions are made by stirring asphalt into water containing the emulsifying agent. The emulsifying mechanism may consist of rapidly rotating propellor blades mounted on a shaft, or a colloid mill. The emulsion is rapidly made if suitable and sufficient emulsifying agent has been added.

Colloid mills are largely used at present for making emulsions. The mixture of bitumen, water, and emulsifying agent, is passed between the surfaces of two discs or truncated cones set very close together. One of the surfaces may be stationary, or both surfaces may revolve at high speed in opposite directions. The colloid mill gives emulsions of finer and more uniform size than stirring with propellor blades.

If the bitumen is solid or semi-solid, it is heated to a liquid state before being emulsified, the water also being heated.

Emulsions tend to break when added to a mineral aggregate, particularly a dense graded aggregate. The reason for this is likely partly chemical and partly mechanical.

Chemically—alkali earth and heavy metal ions present on the surfaces of the aggregate, react with the soaps and clays used as emulsifying agents, and increase the interfacial tension between the water and the bitumen to the point where the emulsion is no longer stable, when coagulation of the bitumen occurs.

Mechanically—the emulsion makes its way to the surfaces of the particles largely by percolation through the pores of dense graded aggregates. This may be considered to be a filtration process in which the mineral aggregate is the filter bed. The breaking of the emulsion is due to a filtration process in which the water, which readily wets (has a high adhesion tension for) the aggregate, is permitted to enter the pores of the aggregate, while the bitumen, which has a much lower adhesion tension for the aggregate, is held back and the emulsion breaks, giving coagulation of the bitumen.

Protective hydrophilic colloids like glue and gelatin, etc., should greatly stabilize bituminous emulsions used for mixing with mineral aggregates. They would delay the reaction between the emulsifying agent and the alkali earth and heavy metal ions, affording chemical protection, and because of their hydrophilic character permit the dispersed particles of bitumen to pass more readily through the pores of the aggregate with the water, affording mechanical protection.

Asphalt Tests and Their Significance

Consistency

Provided that satisfactory bituminous materials can be purchased, the specification which is of possibly greatest importance to the user, concerns the consistency or viscosity of the materials.

In general, low viscosity materials are used for dust laying and priming due to their good penetrating properties; medium viscosity materials are most suitable for road-mix and surface treatments, and high viscosity materials are used as binder for plant-mix construction, although in each case some consideration must also be given to the volatility of the bituminous material, and to the grading of the aggregate with which it is to be used.

Viscosity is usually expressed as seconds Saybolt Furol, and the temperatures at which the viscosities are determined vary with the consistency of the bitumen, being 77 degrees F. for very fluid, and from 140 to 210 degrees F. for the more viscous materials.

The float test, usually run at 122 degrees F., is used to express the consistency of a bitumen too viscous to be determined within reasonable time in a viscosimeter, and too soft for a penetration test. It is frequently used as a measure of the consistency of the residue from the distillation test.

The consistency of semi-solid bitumens is determined by the penetration test, and sometimes is also expressed in terms of softening point. The consistency of solid bitumens is invariably expressed as the temperature at which the material softens (its softening point).

By making viscosity or penetration measurements at two different temperatures on the same material, the susceptibility to temperature change of various bituminous materials can be compared.

Flash Point

The flash point is an indication of fire hazard. It also serves to differentiate between cut-backs and non-cut-backs, and roughly indicates the nature of the solvent used in a cut-back material.

Water and Sediment

These are held to two per cent as a maximum. Both are adulterants, and water causes handling difficulties by frothing if the bituminous materials are strongly heated.

Percentage Penetration Residue

In the past, the percentage of 80 or 100 penetration residue was believed to indicate the "asphalt content" of a bituminous material, and the proportion of the original material which could be relied upon to supply permanent cementitiousness or binding qualities in a road surface.

For bituminous materials from the same source and of the same consistency, cut-backs usually contain a greater percentage of a given penetration residue than non-cut-backs.

Bituminous oils may be compared on the basis of a common consistency by means of further tests on the 80 or 100 penetration residue. It is difficult to say whether comparisons on this basis are justified, since the test itself may alter the materials from various sources differently, and so make the comparisons unjustifiable.

Exposure tests carried out by the U. S. Bureau of Public Roads have indicated that the loss on exposure practically equals the loss on the distillation of a material to 680 degrees F., whereas there appears to be almost no connection between loss on exposure and loss during reduction to 100 penetration residue.

There is a tendency to ignore this test in recent specifications for cut-back asphalt, and in its place to specify that the residue from distillation shall be used for the further necessary tests.

Distillation

The distillation test indicates the nature of the solvent used in cut-back bituminous materials, and also the type of asphaltic base used in their manufacture.

For bituminous materials in general use at the present time, the residue from distillation to 680 degrees F. of an M.C. material is harder than that from an S.C. product, and is softer than the distillation residue from an R.C. product.

The distillation test combined with the viscosity test indicates just how any particular bituminous material should be used. Thus for materials containing a kerosene-type solvent (M.C. cut-backs), the low viscosity bitumens are primers, the medium viscosity materials are binders for dense graded aggregates with road-mix methods, and the high viscosity materials are binders for dense graded aggregates with plant-mix methods of construction. When the distillation test indicates the gasoline-type solvent (R.C. cut-backs), the low and medium viscosity materials are best suited for surface seals or surface treatments, or as binder for open graded aggregates in road-mix construction, while the high viscosity materials are best suited as binder for open graded aggregates in plant-mix construction.

Ductility

The ductility of a bituminous material indicates its ability to withstand stretching. It is considered to be a particularly important test where road surfaces are subjected to extreme ranges of temperature. Ductility may indicate something of the nature of the bituminous material and faulty manufacture, since bituminous substances containing much wax or coarse carbonaceous matter have relatively poor ductility. Very high ductility in a bituminous material is also usually associated with high susceptibility to temperature changes.

The ductility test may be made on the one hundred penetration residue in the case of liquid or semi-liquid bitumens, on the distillation residue, or on the original asphalt if it is a solid.

The test is generally made at 77 degrees F., but may also be made at a lower temperature such as 4 degrees C. Abraham states that there is a temperature for each bituminous material at which it possesses maximum ductility, and the bituminous materials chosen for any project should be those which have their maximum ductility at the average temperature to which the material will be subjected.

Oliensis Test

The Oliensis test has been much used in recent years as a criterion of the so-called homogeneity of a bituminous material. Strictly speaking, no bituminous material is homogeneous since the ultramicroscope reveals it as a two-phase colloid system, consisting, it is believed, of a dispersion of asphaltenes in a solution of resins and oily constituents.

It therefore only requires the use of a filter with sufficiently fine pores to reveal the heterogeneous nature of all bituminous materials by the Oliensis test.

On the other hand, by using a filter with sufficiently large pores, all bituminous materials could be labelled as homogeneous by the Oliensis test.

Since all bitumens are heterogeneous, the Oliensis test as usually run merely creates an arbitrary standard of heterogeneity.

It is very likely that the heterogeneity registered by this test in the cases of some bituminous materials is due to the conditions of the test itself. In some asphalts, such as cracking coil products, the oily constituents are largely aromatic in structure and so particularly good solvents for the asphaltenes. The addition of a naphtha to such a bitumen would be expected to bring about the precipitation of some of the asphaltenes, particularly if the solution of the asphaltenes in the oily constituents was near saturation. In this case the registered heterogeneity would obviously be brought about by the test itself.

The U. S. Bureau of Public Roads have found that the Oliensis test can give no reliable information as to how a bituminous material will behave under exposure. They found that regardless of its so-called homogeneity or heterogeneity before being exposed, in every case the bitumen after exposure was heterogeneous. Exposure residues from both homogeneous and heterogeneous materials were found to have what were believed to be desirable qualities.

The Adhesion of Bituminous Materials to Mineral Aggregates

In recent years asphalt paving technologists have been considerably concerned because most aggregates have a greater adhesion tension for water than for asphaltic oils. An aggregate tends to become coated by the material for which it has the greatest adhesion tension if it is available, and water therefore tends to strip the bitumen from the aggregate in most bituminous surfaces constructed at the present time, resulting in higher maintenance costs.

The problem of making the adhesion tension of aggregates greater for bitumens than for water is one which is at present receiving considerable attention and will receive more in the immediate future.

It has been observed that the higher consistency asphalts have a greater adhesion tension for aggregates than asphalts of low consistency, the asphalts of high consistency having greater adhesion tension for mineral aggregates than water has in some cases.

The higher asphaltene and carbene content of asphalts of high consistency appears to be the reason for their greater adhesion tension for aggregates, since the asphaltenes and carbenes are the most polar constituents present in any quantity in an asphalt.

Mineral aggregates are all polar materials, a polar material being one in which the molecules composing it, or parts of them, are surrounded by electro-magnetic fields due to a separation of the centres of gravity of positive and negative charges of electricity in the molecule or in some part of it. Polar substances tend to be attracted to each other due to an interaction and cancellation of part of their electro-magnetic fields, since this results in a decrease in free energy or increase in entropy of the system, as required by the second law of thermodynamics. A polar material on the other hand has very little attraction for a non-polar material. Examples of non-polar materials are mineral oils, gasoline, and the oily constituents of bituminous oils.

On the basis of the attraction which exists between polar materials, it can be understood why increasing the asphaltene content of a bituminous material should increase its adhesion tension for a mineral aggregate.

However, it has been found that a bituminous oil with a high percentage of asphaltenes may have a smaller adhesion tension for a mineral aggregate than another bitumen with a much lower asphaltene content. It is apparent from this that quality as well as quantity of the asphaltenes must be considered. The greater adhesion tension for mineral aggregates of some bitumens of low asphaltene content could be explained by differences in the chemical constitution of the asphaltenes themselves, whereby they vary in polarity, or because a small percentage of finely divided, highly dispersed asphaltenes gives a bituminous material greater adhesion tension for aggregates than a much larger percentage of partially flocculated asphaltenes.

The adhesion tension of bituminous materials for mineral aggregates can be increased by the addition of fatty acids, sulphonic acids, soaps, etc., which increase the adhesion tension between the bitumens and the mineral surfaces.

The adhesion tension of a bituminous material for an aggregate, especially the fines, and particularly the filler, has a marked effect on the final density that can be secured upon consolidating a bituminous road surface, the greater the adhesion tension between the bituminous material and the aggregate, the greater the final consolidation that can be produced for any given method of compaction, other factors being equal.

It is likely that one or more simple and reliable tests for measuring or indicating the relative adhesion tension between aggregates and bituminous materials, and between aggregates and water, will be evolved in the very near future.

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ANALYSIS AND REVIEW OF PAPERS PREPARED FOR THE SECOND ANNUAL MONTANA BITUMINOUS CONFERENCE ON DEVELOPMENTS AND FUNDAMENTALS OF SUCCESSFUL BITUMINOUS PRACTICE

By F. C. Lang, Professor of Highway Engineering, University of Minnesota, and Engineer of Tests, Inspection and Research, Minnesota Highway Department.

The engineers in the fundamentals division have prepared papers on definite subjects. It was decided that there would be too much repetition and confusion if those representing the different geographical areas were asked to prepare general papers on fundamentals. At the time the subjects were assigned, a request was made that the paper should not be based entirely on data obtained from the state or area in which the author lived. It should be based rather on a comprehensive survey of the data and experience on the assigned subject.

The subjects assigned were as follows:

1. "Preparation of Natural Soils for Bituminous Surfaces," assigned to Mr. Allen of Kansas Highway Commission.

2. "Gravel Bases," assigned to Mr. Stoddard of Iowa State Highway Commission.

3. "Characteristics of Asphaltic Materials," assigned to Mr. McLeod, Department of Highways of Province of Saskatchewan, Canada.

4. "Quantity of Liquid Asphaltic Materials in Dense Graded Mixtures," assigned to C. F. Ramey, Standard Oil Co. of California.

5. "Mineral Aggregates for Dense Graded Mixtures," assigned to Mr. Kushing of the Michigan Highway Department.

6. "Mixing of Aggregates and Bitumens," assigned to Mr. Muir of the Utah State Road Commission.

It is not possible to adequately cover the subject matter in these papers in one hour. A copy of each paper is available for every one and there should be many questions for the authors of these papers to answer.

Two of the papers on Fundamentals have to do with the load carrying capacity of the natural soils and gravel bases. It is commonly recognized that lack of foundation support is responsible for failures on bituminous surfaces, as a bituminous surface does not have beam strength. The area supporting the load increases as some function of the distance between the point where the load is applied and the supporting area. The third, fourth and fifth papers show the best modern practice in the United States on the quality, quantity and design of the materials used in the bituminous surface. The sixth paper deals with the scientific mixing of the aggregates and bitumens. The papers will be discussed in the order listed.

QUANTITY OF LIQUID ASPHALTIC MATERIALS IN DENSE GRADED MIXTURES

By C. F. Ramey

Many engineers, particularly in the Western states, have been endeavoring to develop some rational method for determining the amount of bitumen to use in a dense graded mixture. It has apparently been very difficult to adequately recognize the many variables which affect the amount of bitumen, and yet not make the method of determining the amount of bitumen to use appear complicated. This paper presents in a comprehensive way the formulas and methods which have been used in a large number of states.

The author divides the formulas into two classes:

1. Those based on a sieve analysis using the No. 10 and No. 200 sieves.
2. Those using more sieves, and also taking into account such factors as surface roughness and shape of particles, absorption factor, specific gravity, and film thickness.

The paper includes a discussion of methods used for determining bitumen content in Montana, Wyoming, Iowa, New Mexico, Kansas, North Dakota, Utah, Oregon, Washington, Nebraska, the Province of Saskatchewan, Canada, California, Michigan, Wisconsin and Missouri. The last four use the second, or more complete type of formula.

The type of bituminous material, as well as the aggregate characteristics, may be expected to affect the amount of bitumen used. It is of interest to note the practice in this regard.

Montana has tentatively adopted the use of M.C. for materials tending to have high absorption values, and restricted the use of the S.C. type to materials having low absorption values.

Iowa increases the amount of bituminous material when using a cutback, the increase being approximately the amount of volatile material in the cutback.

New Mexico uses 1¼ to 1½ times more cutback asphalt than a slow curing oil.

Wisconsin states their formulas were originally developed for S.C. materials, and that some modification is necessary when using cutbacks.

Several states give the type of bituminous material used, but do not explain what changes, if any, would be made if changing to another type.

There are several formulas for the amount of bitumen which are based on the size of the aggregate. The New Mexico formula which follows illustrates this type of formula:

$$P = 0.02(a) + 0.07(b) + 0.15(c) + 0.20(d).$$

Where P = percent liquid asphaltic material required
a = ” aggregate between 50 mesh sieve and maximum size.
b = ” ” ” 50 ” sieve and 100 mesh sieve.
c = ” ” ” 100 ” sieve and 200 mesh sieve.
d = ” ” passing 200 ”

All percentages shown by this formula are by weight, on the basis of total untreated dry aggregate, and this formula is applied for S.C. type materials, while for cutback asphalts the recommendation is for an increase in the quantity of liquid asphaltic material 1¼ to 1½ times that indicated by the formula.

In discussing this formula, Ramey says:

“The factors of absorption, film thickness, specific gravity, were purposely not included in this formula, and it is the opinion of the authors of this formula that it is satisfactory for all practical purposes for material within acceptable limits and affords a very simple formula that can readily be used within the limits of refinement obtainable in the field; further, that it permits the field men to continue their work without having to consult tables or depend on the laboratories.”

The California method illustrates the second classification where other factors than size of the particle are taken into consideration when calculating the amount of bituminous material to use.

Ramey states that, "This method, as outlined by Mr. Hveem, is, in general, based on analyzing the material by sieving and determining surface area values from sieving analysis with recognition of the following factors:

First: The optimum liquid asphaltic material content is directly related to the surface capacity of the aggregate. This surface capacity is affected by three factors, each of which may vary independently of the others:

(a) Most important is variation in surface area due to variation in grading. For the same weight, small particles have a greater surface area than large ones.

(b) Variation in surface area due to shape and character of surface of particles.

(c) Variation in absorption capacity of different aggregates.

Second: It has been established that the thickness of oil film or coverage factor must be varied according to the average size of the particles."

Table 1 shows the surface area constants for the various sieve sizes. These constants are necessary because the finer particles must have thinner bituminous films than the larger sizes.

The following from a letter written by Hveem of California to Ramey gives additional reasons for the variation in constants for the different sizes.

"We have received some criticism of the low values which are used as constants for the Surface Area of dusts passing 200 mesh. While the constants are unquestionably lower than the true superficial area of most fillers, it appears that the increased surface of very fine dusts does not have a continuous increased effect; in other words, particles probably become so small as to be "lost" in the coatings on the coarse aggregate and do not require a proportional allowance for Surface Area. At any rate, experimental calculations using higher figures for the surface area of Dusts have not indicated any improvement."

Figure No. 1 shows how the amount of bituminous material to use is computed after the surface area of aggregates has been determined. The procedure is shown on the chart.

Mr. Hveem states in his letter to Ramey that, "It appears to be a common impression that the Surface Area Method is a somewhat lengthy involved process. As a matter of fact, I do not believe that it requires any more time in the application than is the case with the short type of formula. In this laboratory, with the aid of a slide rule and the attached tables and charts, a computation is readily made in less than two minutes. While several pages of instructions and charts are required, the actual determination of oil content may be quickly made."

The above description illustrates the method of attacking this problem in California. There is not time to describe the method in detail.

It is evident that some rational method of design is desirable. The judgment of many field engineers may be excellent, but experience has shown that through inexperience or poor judgment some will make mistakes.

ANALYSIS AND SUMMARY MIXING OF AGGREGATES AND BITUMENS

By Levi Muir

This was a difficult assignment for a paper on fundamentals. As previously stated, it is generally difficult to decide what portion of a subject properly belongs under fundamentals and what should be classified under construction or maintenance. That is particularly true of this assignment.

This paper may be divided into the following subjects:

1. Theoretical principles involved in mixing and results accomplished.
2. Advantages and disadvantages of central plant and road mixing.
3. Description of some typical types of mixtures.

Theoretical Principles Involved in Mixing and Results Accomplished

Muir has made a number of statements on general principles under this heading. A few of these are as follows:

(1) "Granting the materials have satisfactory reaction with the bitumen, wide variations of gradings have been found to give satisfactory results when subjected to the destructive forces of traffic."

(2) "Most investigators agree that the optimum amount of bitumen is the largest percentage the material will carry and still retain sufficient stability under traffic."

(3) "Adequate strength and durability of mineral aggregate and durability of the bituminous binders are necessary."

(4) "In mixing materials on the road, it is essential that the bitumen be thoroughly distributed among the fines and that no clods of free oil be present."

(5) "One of the most difficult parts of mixing is to conduct the operation so that the proper percentage of bitumen is present at all times."

The author then, under the general subject of film thickness, gives the following description of an apparatus developed in California for determining the amount of bitumen on minus 10 mesh material:

"A cylinder of the mixture is formed at a temperature of 300 degrees F. and six thousand pounds per square inch pressure in a two-inch diameter mould. The mould is recessed at the bottom to a slightly larger diameter to permit the placing of twenty thicknesses of filter paper. When the pressure is applied to the mixture, free bitumen on the surface of the aggregate particles is forced out through the filter papers. For rich mixtures, binder may be forced through the entire number. Drier mixtures may show only two or three papers stained. After compressing the material, the cylinder is forced from the mould and later tested in the Hubbard-Field machine at a temperature of 140 degrees F.

For field control a Black Hawk recording jack of 20,000 lb. capacity may be used. The stain number obtained in the field is compared with laboratory curves which have been prepared for these particular materials. In this way the field engineer can readily determine whether the mix is too rich or too lean."

A description of the results of some laboratory studies with this apparatus is given in the paper. The results are shown graphically on the attached cross-section sheet.

The conclusions on the laboratory study are as follows:

"These studies show a very gradual increase in stain numbers for increase in bitumen ratio to a certain point where the curve takes a sharp turn upward. After this point is reached any additional binder adds greatly to the number of filter papers stained. Maximum stability usually occurs at the break in the curve. The specific gravities appeared rather erratic. A pycnometer method was used for this test. The time required to fill the pycnometer may have caused error due to absorption of water by the sample. Some overflow method will be used for future tests."

Muir is of the opinion that before such a method is inaugurated by any highway department, checks should be made on old surfaces in order to establish test limits.

The author very briefly describes methods of mixing aggregates and bitumens. This will not be commented on at this time except to quote the following:

(1) "Medium curing cutbacks are almost universally employed as binder for plant mixtures. As the diluents boil at low temperatures, it is not good practice to heat the aggregates above 225 degrees F. Any higher temperature than this will cause very serious loss of binder."

(2) "The moisture trouble is always present and it is usually not possible to dry the materials to a point below three-fourths of one per cent without danger of changing the bitumen by heat."

Advantages and Disadvantages of Central Plant and Road Mixing

The plant mix can be used to best advantage on large jobs in humid areas where the aggregate has not been previously placed on the road. Muir states that the plant mix is adapted to mass production. The plant mix can be more closely controlled than road mix and about 20 per cent less bitumen is required. A higher viscosity asphaltic material can be used. The plant mix interferes less with traffic during construction.

The road mix method is very well adapted for use in the arid and desert regions, and also on small jobs where the cost of moving in plant mix equipment would be excessive.

Road mixing utilizes machinery used by contractors and highway departments for other types of road work. Gravel can be hauled directly from one or more sources to the road. It is not necessary to haul all of the materials to one central point.

Description of some typical types of mixtures. Muir describes the composition of the close and open graded types of bituminous mixtures for low cost roads. He states that on account of the availability of gravel, and the resulting lower cost, most of the bituminous roads in the western part of the United States are of the close graded type. The open graded types are sometimes used to resurface old roads that have become uneven under traffic.

CHARACTERISTICS OF ASPHALTIC MATERIALS

By N. W. McLeod

To some it may appear that a paper of this character is out of place at a bituminous conference which is largely attended by engineers who are primarily interested in road construction and maintenance. It was our idea, however, that the so-called practical road engineers would be interested in a paper such as Mr. MacKenzie and Mr. McLeod have prepared. As road building becomes more and more of a science and less and less of a trade, engineers are going to find that success can only be attained by an ever increasing knowledge of materials and the basic principles governing their use. Highway engineering today is based entirely on the motor vehicle, and yet we have only had the motor vehicle in common use for a few years, and there have been many changes in the vehicle during that time. There has been very little time for engineers to learn how to apply science in building roads for the motor vehicle. The future highway engineer must have a thorough understanding of the fundamental sciences and how to apply them for his own needs. Competition will probably be so keen that there will be no jobs for highway engineers who are not so qualified.

This paper is divided into the following subjects:

Chemical Composition
Origin
Manufacture
Tests and Their Significance
Adhesion to Mineral Aggregates
Bibliography

Everyone interested in asphaltic road materials should carefully read and study this paper. There is only time to mention a few items in this summary.

Chemical Composition

All bituminous materials are hydrocarbons, that is, largely made up of carbon and hydrogen atoms. The atoms unite to form the molecule in two distinct different patterns, the open chain (aliphatic) and the cyclic series (aromatic). These are illustrated in the paper.

The characteristics of the bituminous material vary not only according to which series or family it belongs, but also according to the size of the molecule. There is an infinite number of different combinations, each having different physical properties. In general, as the number of carbon atoms in a molecule increase, it passes at ordinary temperatures, from a gas through a liquid to a solid state. To further complicate matters, we have the saturated and unsaturated molecules. A carbon atom possesses four valences or bonds which must be attached to another atom. When there are too many carbon atoms present, as compared with the hydrogen atoms, there may be two or three valences used to connect the carbon atoms. The molecule is not satisfied with such an arrangement, and at the first good opportunity will change to the one link arrangement. The physical properties of the material change when the molecular arrangement of the carbon and hydrogen atoms change. Such a material might not be stable in a road.

The author states that very little work has as yet been done on the chemistry of asphalts and asphaltic oils. Therefore, it would appear that the control of the material must depend on physical tests, although it is desirable, for an understanding of the behavior of the material, to have some knowledge of the chemistry of hydrocarbons.

Origin

The author of the paper presents some theories concerning the origin of the different bituminous materials.

While this subject is too vague to be of much practical value to road engineers, it might not be amiss to mention briefly the origin of oil asphalt, natural asphalt and rock asphalt. These terms are commonly used in specifications.

Asphalt is obtained from certain petroleums and may be either obtained in a short period of time by artificial distillation or in a long period of time by natural evaporation. The natural asphalts such as Trinidad and Bermudez, are examples of the latter.

There is a difference in the physical properties of the residues obtained by evaporation of the more volatile portions of crude petroleum oils obtained from different places in the United States. The source of the crude oil may be of importance if asphalt having certain characteristics is desired.

In some areas a porous rock such as sandstone and limestone has become naturally impregnated with an asphaltic base petroleum, and we have rock asphalt. The asphalt content may vary widely in different parts of a quarry and the quantity and quality may vary between different quarries.

Manufacture

It was stated under "Composition" that a gas has a smaller number of carbon atoms in a molecule than a liquid, and a liquid has a smaller number of carbon atoms than a solid. The lighter liquids, such as gasoline, may be obtained from crude oil by heating to a temperature necessary to separate them according to their boiling points. This is termed fractional distillation and there should be no change in the composition of the molecule. There is a large demand for gasoline in this motor age and it was discovered that if more heat and pressure were used during the distillation process, the molecules could be broken so that more gasoline would be obtained. This process is called cracking. Figure 2 on the last page is a sketch of a cracking process and its operation is described by the authors. Engineers are inclined to question the quality of cracked residues for road work. Specifications are usually written with the intention of excluding cracked residues from cutbacks and asphalt cements and some slow curing materials. There is some question as to whether this requirement is always met.

The physical characteristics of residues obtained from cracking are probably not as permanent, on the whole, as residues obtained from fractional distillations. The molecule which has been disrupted in the cracking process may later recombine to form some new compounds with different physical characteristics.

The authors have described the oxidation process by means of a sketch. Among the uses of oxidized asphalts are as a filler for brick pavements and roofing material. It makes an asphalt less susceptible to temperature changes, but also lowers its cementitiousness and ductility.

There are in general two methods other than heat of making an asphalt cement thin enough to coat aggregates. One is to thin it with a volatile substance, and the other is to disperse the asphalts in water as an emulsion. The authors describe each process.

Asphalt Tests and Their Significance

It is to be hoped that we may have some interesting discussion on this subject. The asphalt industry and the Bureau of Public Roads have tried to standardize the tests and test limits for liquid asphaltic materials. They were not entirely successful in this undertaking. The basic character of the material varied so in different areas that a uniform specification seemed to be an impossibility. As an illustration, on some S.C. materials used in the Mississippi Valley states there is little, if any, distillate at 680 degrees F. Therefore, no quality tests can be made on the residue which could not be made on the original oil.

Some may wish to discuss some tests not named by the authors. It is to be hoped that they will do so.

Many engineers consider that tests generally used in specifications at the present time do not assure a satisfactory product, and so they are trying to develop new tests. In doing so, they naturally concentrate on their own particular needs.

Many engineers agree that there are three essential properties for asphalt cements. These are:

1. Consistency
2. Cementitiousness
3. Durability

We have satisfactory methods for measuring the first, but not for the other two. Asphalt test methods have been based on identifying a material which has been successfully used. There is no assurance that other materials not meeting the three listed fundamental requirements will be excluded, or that some good materials may not be included.

Adhesion to Mineral Aggregates

This is a subject that engineers must learn more about in the future. The following quotation gives the author's viewpoint:

"In recent years asphalt paving technologists have been considerably concerned because most aggregates have a greater adhesion tension for water than for asphaltic oils. An aggregate tends to become coated by the material for which it has the greatest adhesion tension if it is available, and water therefore tends to strip the bitumen from the aggregate in most bituminous surfaces constructed at the present time, resulting in higher maintenance costs."

It is possible that the bituminous engineer of the future will have to investigate the likes and dislikes of the bitumens and the aggregates. He will then endeavor to avoid any intermingling of bitumens and aggregates which are repulsive to each other. When this cannot be done, he may have to introduce some other substances to serve as peacemakers.

SUMMARY AND ANALYSIS MINERAL AGGREGATES FOR DENSE GRADED BITUMINOUS MIXTURES

By J. W. Kushing

It is apparent in the first two paragraphs that the authors did not have high type pavements in mind when they wrote this paper. The title is broad enough to include such pavements, but, as the authors evidently realized, this conference is mostly concerned with low cost roads.

This paper is based to a large extent on the information obtained from a comprehensive questionnaire which was sent to the Province of Saskatchewan and nineteen states participating in this conference. The replies received to this questionnaire are given in a table which is attached to the paper. This is, without doubt, the best summary of information on this subject in the United States.

In this paper the subject matter is divided into three major divisions: quality, grading and field control.

Quality

In the first paragraph, under the general heading of Quality, on page 2, it is stated that the quality or physical properties of a mineral aggregate is based on its ability to **resist traffic abrasion, and crushing in construction, internal stability, and resistance to weathering.**

Traffic Abrasion, and Resistance to Crushing in Construction.

The standard laboratory tests which have been used for measuring the resistance to traffic abrasion and crushing are the Deval

Abrasion, Los Angeles Rattler, Page Impact, and Lithological Count in which emphasis is placed upon the soft and non-durable particles.

The Deval Abrasion is quite widely used on both gravel and stone; one state, California, uses the Los Angeles Rattler on stone and gravel; one state, Missouri, uses the toughness test on stone; and a few states specify maximum limits for the amount of soft and non-durable particles. Some other miscellaneous tests are shown in the table. The Los Angeles Rattler is a rather new method of testing, and it is probable that it will supercede the Deval Abrasion test after more data is obtained with it.

There is a question as to how severe the requirements should be for the quality of the aggregates in low cost bituminous roads. On this subject the authors state: "Obviously, no definite test limits can be set up which will apply to all regions. They will vary for each region, depending upon what type of materials are economically available." Perhaps we could have some discussion on this subject today. Are there any failures of bituminous surfaces which can be attributed to soft aggregates? Has any one established any relationship between length of economical haul and the hardness of aggregates?

Internal Stability: The authors are of the opinion that the shape of the particle and the character of the surface of the aggregates are important from the standpoint of stability and non-skid properties in the finished surface. They consider that it is desirable to have angularity, a rough surface, and some porosity. The replies to the questionnaire show a trend toward requiring a percentage of crushed particles. The authors then refer to tests which have been used for measuring stability and close their discussion on this subject with this statement: "It appears that a test of this nature could be used to measure the effect of crushed particles in a dense graded mixture, but additional research work along the lines indicated will be required before the merits of crushed material in dense graded bituminous mixtures can be established."

Resistance to Weathering:

As tests for determining durability the authors give soundness, water-asphalt preferential, and swell tests.

The soundness test, which is made to show the resistance of an aggregate to disintegration by freezing and thawing, is not specified by many states. These is some question as to how rigid this requirement should be for aggregates more or less surrounded by an impervious self-healing binder. The conditions are entirely different than they are in Portland Cement concrete.

Water Asphalt Preferential and Swell Tests: Some materials have a greater affinity for water than for asphalt. When asphaltic mixtures become wet, the asphalt tends to strip off from such materials. The water asphalt preferential and swell tests are made to identify materials which would separate from the bitumen in the presence of water. Stanton and Hveem state in their paper on low cost bituminous pavements, Highway Research Board, Part 2, Fourteenth Annual Proceedings, that the water asphalt preferential test is made on minus 200 mesh sieve material, but the grading used in actual construction may be used in the swell test. The authors state that most states prefer the swell test. The comments in the table are very interesting. It is ineresting to note that most of the comments and proposed test limits come from the western states.

Grading

The authors state that, "The ideal grading of the fine and coarse aggregate in dense graded mixtures is that in which the final mixture shall almost attain maximum density, thus resulting in maximum stability with minimum use of binding material, thereby obtaining an economical low cost surface." In order to almost obtain maximum density, fillers must be used. The replies to the question, "What do you think is the importance of the portion passing the No. 200 sieve in the mixture?" are interesting. There are a number of warnings against using too much filler.

The authors state that

1. There is a growing tendency to use gradings giving coarser texture rather than maximum density.
2. A maximum size of one inch is preferred.
3. High percentages of fillers may produce critical mixtures which are subject to bleeding in warm weather.

Tentative Dense Graded Specifications: After studying the replies to their questionnaire, a tentative specification to show trends is given on page 8.

Field Control

In discussing laboratory and field control, the authors state: "These two factors are not separate, and successful control depends upon the proper relationship existing between laboratory and field inspection forces as experience has shown that control of aggregate gradings is made more positive by a double check between these two organizations."

Figure No. 6 shows the Michigan organization for the testing and inspection of materials for dense graded bituminous mixtures. You will note the interrelationship between the field inspection and the laboratory. It also shows the number of samples tested. One cannot emphasize too much the desirability of handling work in some such manner as is illustrated in this figure.

ANALYSIS AND SUMMARY
FUNDAMENTALS OF GRAVEL BASE CONSTRUCTION

A. E. Stoddard

On most natural soils it has been found necessary to construct some type of base between the bituminous wearing surface and the underlying soils. On projects where selected soils have been compacted to a maximum density in the upper portion of the subgrade, the thickness of the base necessary should be less than on a subgrade constructed by the usual grading methods. Formulas given for the design of flexible surfaces are based upon the principle that the bearing pressures decrease as they are transmitted through the thickness of the base. On this basis, the author of this paper states: "Theoretically it should be most economical to construct a base in which the stability will vary throughout the depth from high bearing pressure needed just under the surface to the low bearing pressure permitted on the subgrade." It is possible this might be accomplished in ordinary construction by constructing the base in layers, each layer nearer the surface having greater stability than the layer immediately below. The upper portion of the subgrade which had been compacted to a maximum density would then act as a sub-base, having greater stability than the soil below.

It is commonly recognized that flexible bituminous surfaces frequently fail because of inadequate foundation support. We need more data on the design and construction of bases and subbases for this type of surface. Inasmuch as gravel is extensively used as a base material, Mr. Stoddard of the Iowa Highway Commission was asked to prepare a paper upon "Fundamentals of Gravel Base Construction."

Design of the Thickness

The author has reviewed the various formulas for flexible pavement design. These formulas all assume that the angle of load distribution is 45 degrees, and that the pressure on the subgrade is uniform over the loaded area. Stoddard points out that this angle may not be 45 degrees, but may be as small as 34 degrees as given by Hogentogler for the angle of internal friction on either sand or cemented gravel. Furthermore, quoting from the paper: "It seems more logical to assume that the load will not be uniformly distributed, but will be represented by a solid volume, the maximum ordinate of which is equal to the safe bearing pressure on the soil and tapering to zero at the edge of the area. For Professor Downs' and Mr. Grey's formulas such a distribution of pressure would reduce the supporting power for a given thickness to about one-third the previous figure or require approximately 1.73 times the depth. For Harger & Bonney's formula such a distribution would reduce the supporting power to less than one-half of the previous figure, the exact reduction depending upon the relation between the width of tire and the depth of surfacing."

The author then points out that in order to apply the formulas it is necessary to determine what will be the safe bearing load for the subgrade soils to be encountered. It will be necessary to determine this not only at the surface but to a depth which will insure that the subsoil layers will be capable of withstanding the pressures which will be transmitted to them. After quoting Hogentogler on some theoretical supporting values of soils, Stoddard states: "The correct classification of the subgrade material encountered and assignment of correct bearing value are still matters of judgment and experience in knowing what will be the 'worst condition' of the materials encountered."

Formulas of this character are interesting and instructive, but are based on too many questionable assumptions for general acceptance. It is to be hoped that research will soon provide a satisfactory tool or method for evaluating subgrade support.

Design of the Stabilized Soil, Sand, Gravel Mix

To understand the mechanics of base stability we should first become acquainted with the functions of the various materials which make up the mix. The paper quotes a paragraph from the

Progress Report of the Committee on Stabilized Soil of the Highway Research Board as follows:

"The coarse aggregates and coarse sands furnish hardness and structural strength. Fine sand adds an embedment support to the coarse sand. Silt acts as filler to prevent the granular particles from rocking. Clay and colloidal particles provide pores minute enough to cause the connecting moisture films to have high cohesion."

As a result of research the engineer now has a definite basis for proportioning the stone, sand, silt and clay in a stabilized mixture. Stoddard includes in his paper, grading curves and methods for determining quality and quantity of binder.

Mixing Operations

Road Mix:

The coarse aggregates and binder are proportioned to give the required grading. Generally, the pulverizing of the binder soil offers the greatest difficulty. The binder soil may be pulverized either in the pit or out on the road. If the soil is pulverized in the binder pit, it is spread out in thin layers and allowed to dry sufficiently so that it will break down when worked over with the ordinary equipment. Passing through shaker screens also aids in pulverizing the clay and removing clods. If the binder is hauled onto the road, it is spread out and allowed to dry before pulverizing. Equipment for pulverizing will vary with different contractors. The author of this paper mentions the disc, the tooth harrow, the wood drag and the Roto-mix.

When the binder has been pulverized so that 80 to 90 per cent passes a No. 4 sieve, it is bladed and mixed with the coarse aggregates. It is usually necessary to add water at this stage to facilitate mixing and compacting. The total amount of water necessary ranges from 5 to 8 per cent by weight of the total mix.

Plant Mix:

The dust from pulverizing clay and the road mixing operations are annoying to the general public, especially in the city and on heavily traveled highways. To eliminate these nuisances, and also to obtain more uniform proportioning and mixing, it is in certain instances desirable to use the plant mix method. The method of mix which will be the more costly will depend largely upon local conditions.

In Minnesota we are now finishing a 14-mile project on which we used a portable plant manufactured by the Pioneer Gravel

Manufacturing Company of Minneapolis. This plant has been operating approximately 20 hours a day with an average production of 85 tons of mixed material per hour. This plant is capable of shredding and pulverizing the binder soil even when it contains as high as 25 per cent moisture. It has been our experience that there have been less delays due to bad weather on plant mix than on road mix jobs.

Consolidation of the Mix

Consolidation of the mixture is an important item because a low percentage of voids is necessary to prevent softening from surface water. To obtain proper compaction, the base course should be placed in layers not exceeding three inches, and proper moisture content should be maintained in the mix. Pneumatic tired rollers appear to be more efficient than the smooth steel tired rollers, although the steel tired roller gives a smoother surface. The sheepsfoot or tamping roller has not been used as extensively as the other rollers, but it may be a desirable piece of equipment to use on certain jobs. The Parsons Company has recently produced a roller composed of about 12 cast iron wheels which may be suitable for gravel base consolidation.

Stabilized bases have been constructed which have a density of 150 pounds per cubic foot. This is equivalent to about 9 or 10 per cent total voids.

Use of Admixtures

Calcium and sodium chlorides have been extensively used as admixtures. The solution of these salts have lower vapor pressures than water, and consequently have slower evaporation rates. They are effective in maintaining a more uniform moisture content in the mix during compaction. Stoddard also describes the use of bituminous and Portland cement as admixtures.

Maintenance

There is some question as to how soon it is advisable to lay the bituminous surface after the stabilized gravel base construction is finished. Additional density and uniformity can probably be obtained by allowing the base to carry traffic for a few weeks. During this period, however, the base should be properly maintained in a dustless condition.

It is absolutely essential that the base be maintained with the proper crown. No blading or smoothing can be done, however, unless the base is wet. During dry spells, any pot holes that develop should be patched with a stabilized mixture containing proper moisture content and either calcium or sodium chloride.

A bibliography is given on the last two pages. This should be very helpful to those who wish to study this subject.

PREPARATION OF NATURAL SOILS FOR BITUMINOUS SURFACES

By Kansas State Highway Commission

The "Preparation of Natural Soils for Bituminous Surfaces" is a subject which is receiving more and more thought by those responsible for designing roads, particularly the so-called low cost roads. It appears that the only satisfactory solution of the Farm to Market road problem lies in the development of methods to utilize natural local soils for sub-base, bases and, in some instances, even wearing courses.

Requirements for Good Subgrades

The authors give three general requirements for good subgrades: (a) Ample Bearing Power, (2) Performance, and (3) Uniformity.

Ample Bearing

The Kansas Highway Department has made studies with the Proctor needle for measuring subgrade support. These studies were made both in the field and in the laboratory.

The field tests were made on approximately twenty miles of roads located in the oil fields. The traffic census on these roads showed a traffic count of 1250 vehicles per day, of which a considerable portion were heavy trucks. No failures were found where the needle reading of the subgrade exceeded 800 pounds per square inch. On some portions where the thickness of the dense surface layer was greater, the surface was in good condition even though the needle reading showed 600 pounds per square inch. The authors do not give any information as to thickness of surface layer and whether or not give any intermediate layer or base between the subgrade and the bituminous surface. It would be very helpful in design if we could obtain data which would show the thickness of stabilized gravel base necessary for different subgrade supports as measured by the Proctor needle. It is to be hoped that more field studies will be made, particularly when the subgrade is in its most unstable condition.

The laboratory studies were made to ascertain at what maximum moisture content and minimum density a particular soil will furnish sufficient bearing capacity as a subgrade for bituminous surfaces. This information is of value both in design and construction. It gives the design engineer some basis for computing the required thickness of the wearing surface and base, and it gives the construction engineer a yardstick for measuring the compaction or density of the roadbed. One must not overlook the possibility of high moisture content in subgrades when the natural evaporation is prevented by bituminous surfaces.

Permanence

On this subject the authors state: "There is no single condition of moisture content and density at which a soil will remain permanently. * * * Soils having moisture contents during compaction sufficient to result in a condition of maximum density with the pore spaces as nearly as possible filled with water after compaction offer greater resistance to the gain of moisture by absorption or the loss of moisture by evaporation than do soils compacted at any other condition." The ideal moisture content is generally referred to as the optimum moisture content.

Some soil studies made in the Minnesota Highway Department laboratory substantiate this. There is still a question as to the change in density of a compacted subgrade soil after long exposure, particularly when subjected to a number of freezing and thawing cycles. When subgrade soils are compacted at or near the optimum moisture content it might be well to allow a factor of safety when designing bases. This factor of safety is to allow for the decrease in supporting value of the base after long exposure to the elements.

Uniformity

Non-uniformity may exist in either one or two ways. The subgrade may be uniform in texture but non-uniform in density, or the subgrade soils themselves may be non-uniform. Of course, if we could keep the subgrade reasonably dry at all times, uniformity would not be an important item to consider. Inasmuch as this is an impossibility, however, it is necessary that we obtain as uniform a subgrade as possible. Slight non-uniformity of subgrade soils might be compensated for by varying the thickness of the base. This would require a soil survey.

Preparation of Soils During or After Construction

The principles set up for efficient utilization of natural soils during grading operations appear fundamentally sound. It is unfortunate that more detail was not given as to just how the work was carried out. There are many difficulties which must be overcome by those pioneering in the application of the soil principles developed in the laboratory. One of the most difficult operations will be in preparing the soil at the optimum moisture content to facilitate compaction.

One of the first steps to be taken when using the more refined grading methods is to use selected soils in the upper portion of the grade and to compact these soils at or near optimum moisture content. By using these methods we should be able to reduce the thickness of base generally required to support traffic, thereby realizing a savings on the completed job.

Corrective Treatments

Drainage. Poor drainage conditions are eliminated by either one or more of the following methods outlined by the authors: (1) French drains, laid out either in a chevron or parallel system; (2) Perforated pipe and drain tile; (3) Crushed stone to act both as a French drain and a base course; and (4) Raising of the grade with either porous stone or earth.

The occurrence of shrinkage cracks that extend through the bituminous mat and allow infiltration of surface water which softens the subgrade is apparently a recent development.

Treatment of Frost Boils and Frost Heaves

The reasons for the occurrence of frost boils and frost heaves have been fairly well understood for some time. We now need more information relative to the most economical methods for treatment. It is hoped that engineers will continue to accumulate data on methods of correction, and at a conference in the near future we may have a paper devoted entirely to this subject.

Preparation of Soils—The Use of Admixtures

The second sentence in the first paragraph under this heading states: "When stability can neither be obtained nor maintained for a satisfactory length of time under good road construction and maintenance practice, it becomes necessary to provide both support and permanence by the construction of some type of base or by improving the soil by the incorporation of some stabilizing admixture." The two methods of increasing stability by the use of admixtures as described in this paper are (1) by improving the grading of the soil, resulting in a mechanically stable mixture, and (2) by providing binders insoluble in water. This is a new development, and I hope that we may have some discussions on methods of using the various admixtures for improving stability.

A bituminous treatment should provide a cohesive film about the soil particles sufficiently strong enough to prevent capillary water from pushing the grains apart and rendering the soil unstable. It has been a question to me as to whether this could be practically obtained.

The authors give the following summary and conclusions:

"The economy with which subgrades for bituminous mats are prepared depend upon the nature of the soils, the care with which they are placed and the protection they are given toward maintaining the desired conditions. Climatic conditions play a large part and are often the deciding factor as to whether or not admixtures must be used or bases constructed to increase the supporting value of the soil. Lack of adequate drainage for both surface and subsurface often make it appear that special bases of stabilization are required, when in reality the failures occur only at those places where proper drainage is lacking. When it is apparent that stabilization is necessary, considerable thought should be given toward which type of admixtures will best fit the particular soil conditions—or whether it would be more economical to construct a base course."

To aid those who may wish to study this subject a bibliography of the literature on the subject is given.

DISCUSSION ON DEVELOPMENTS AND FUNDAMENTALS OF SUCCESSFUL BITUMINOUS PRACTICE

CONFERENCE BOARD

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Prof. Lang: The first paper open for discussion will be the Kansas paper, the title of which is "The Preparation of Natural Soils for Bituminous Surfaces." Are there any questions?

Mr. Kirby:
Utah

I would like to submit this question. I am wondering if any state has studied the hydrogen-ion concentration of soil solutions with reference to stability of material both before and after oiling. Also as to the effect on preferential wetting of materials subsequently by both oil and water.

Mr. Reagel:
Missouri

Mr. Chairman, that question is being studied in connection with Dr. Winterkorn's work which is the cooperative research between the Bureau of Public Roads, the Missouri University and the Missouri Highway Department, and in that work he is changing the character of ions on the surface of the soil colloids by chemical treatment. In checking in on the hydrogen, calcium, sodium, and potassium ions he advises that in the case of hydrogen ions on the surface he obtains the least desirable condition as measured by physical tests such as adsorption. In the case of surface ions being hydrogen he gets a greater amount of adsorption than he does with the heavier ions, the intake of water being considerably higher than in the case of heavier ions.

Prof. Lang: Can you refer to any publication?

Mr. Reagel:
Missouri

He has published some of the data in "Soil Science," November 1935 and January 1936, and is about ready to make a further report in cooperation with the bureau.

Mr. Benedict:
B. P. R.

You will find an article on Stabilized Soil Roads in the May, 1936, issue of "Public Roads."

Prof. Lang: Has anyone else a question? In the preparation of natural soils, are any of the states doing anything toward improving the stability of the natural soils in the grading process? Some of you have some work on this, have you not? Have any of you done any work in measuring the density or specifying it?

Dr. Loy: Standard Oil Wyoming
It seems to me, Mr. Chairman, that the State of Kansas did something along this line three or four years ago. I wonder if their representative here might enlighten us along that line.

Mr. Johnson: Kansas
Although we have for several years measured the density of soils, our first attempt to specify the density of soils in fills was early in 1934. Since that time we have required that a soil be compacted to a predetermined density regardless of whether the work being done is new earthwork construction or reconstruction of old grades for bituminous surfaces. In reconstructing old bituminous mats we scarify the base and reroll it as the desired moisture content to meet certain density requirements.

Mr. Kushing: Michigan
May I ask to what depth do you carry that compaction?

Mr. Johnson: Kansas
If you mean the depth to which we carry compaction in reconstruction of old mats, the soil is torn loose to a depth of from six to eighteen inches, depending upon the soil itself, and the existing moisture content and density. In some instances where the soil is of an undesirable nature we excavate and remove the soil and replace it with selected soil which is then rolled into place.

Prof. Lang: I believe that some states, perhaps a western one, require that their fills, or some portion of them, should be of a certain density. I understand the density is determined by filling the hole from which the soil sample was taken with a known volume of sand or water in bags.

Prof. Moyer: Iowa — I think that is California.

Mr. Kushing: Michigan — Ohio has done some experimental work on it, but I do not have the specifications. We have also done a small amount of experimental work in this connection.

Prof. Lang: Can you tell us something about the work that you are doing?

Mr. Kushing: Michigan — The experimental work which we did was in connection with a fill about 18 inches in depth which consists of a soil which we classify as our Miami series. This soil contains about 36% clay and 37% silt. According to all recommendations we felt that it was not satisfactory fill material, but after having made some study of the Proctor methods we decided to utilize the Proctor method in fill construction and control, and we obtained very fine results. Of course, we have not had the fill go through a winter yet, but the appearance would indicate to us that we will obtain very satisfactory results.

Mr. Benedict: B. P. R. — Professor Moyer referred to the California method for determining relative fill compaction. This method has been successfully used in the Northwest also. A hole is bored in the compacted fill, using a standard post hole auger and carefully saving all of the soil that is taken out. The volume which this material occupied in the fill is determined by refilling the hole with dry sand, or by lowering into the hole a large flexible rubber sack of the same diameter and filling this sack with water to the top of the hole. The soil that was removed is then taken into the laboratory and its maximum compaction is obtained. Knowing the volume which the soil occupied in the fill and its volume when completely compacted, a relative compaction factor can then be computed.

The weakness of this method appears to be its lack of adaptability to the rapid field determinations which are necessary during construction, but it is valuable in determining whether or not a completed fill has attained a sufficient degree of compaction to support a rigid surfacing.

Prof. Lang: Another suggestion brought up in the Kansas paper concerns the use of admixtures. Are there any of the states represented that have had any experience with admixtures with the natural soil?

Mr. Powers:
Arizona

We have had comparatively limited experience with it in northern Arizona where we have disintegrated shale. We took about a quarter of a mile of bad material and used emulsion, treating approximately five inches of soil. There are no failures to date and it does not look like there are going to be any.

On both adjoining sections we placed base course. Enormous amounts of moisture accumulated in it, causing failures, whereas the one-quarter mile remains very satisfactory under all conditions.

Prof. Lang: Slides will be shown tomorrow on Missouri's method of using admixtures.

Mr. Powers:
Arizona

There was a very noticeable tendency for the asphalt to migrate in the soil which I have mentioned, and whether it took place subsequent or at the time of the laydown we have been unable to determine.

Prof. Lang: I would like to call your attention, at this time, to the fact that both Drainage and Frost Boils are also included in this subject.

Mr. Buchanan:
Idaho

Idaho has just completed 4000 feet of experimental construction using emulsified asphalt as an admixture. There are four 1000-foot sections in which we tried different treatments. The first 1000 feet has a 4-inch layer of coarse sand interposed in the fill, above which is 12 inches of natural soil fill, and on top of that is a 2-inch layer of emulsion treated soil. Another 1000 feet is exactly like the first, except that the 4-inch sand layer is left out. There is a third 1000-foot section which has a 6-inch treated layer. The treated soil of these three sections had, as I recall, 30% passing the 200-mesh sieve. Then we had a 1000-foot section which we treated with emulsion, the soil of which all passed a 200-mesh sieve. In fact it contained about 60% silt. The work has just been completed, and no costs are available yet and there is no indication as to how it will perform.

Prof. Lang: Is there anything more on this particular discussion of frost boils?

Mr. Olmstead:
Michigan

In the early part of 1928-1929 Michigan carried out an extensive investigation to determine the cause of frost action and thereby eliminate the damage caused both to rigid and flexible road surfaces by frost action in the subgrade. The results of these investigations have been reported in the proceedings of the tenth and eleventh annual meetings of the Highway Research Board. However, it might be advisable to sum up the conclusions the department has drawn from these investigations.

All subgrade soils, grading from fine to coarse, provided their voids are filled with water, are subject to detrimental frost action during freezing weather. The voids in the coarser soil textures must be filled with free water before detrimental frost action occurs. Thus, the corrective measures for these soil textures need only be the installation of proper drainage to lower the free water to below the frost line. Tile edge drains or stone bleeders are generally sufficient to eliminate the high water table, although in some cases it may be more economical to raise the grade over these sections of poorly drained subgrades.

The voids in the finer soil textures are filled by capillary moisture which cannot be removed by artificial drainage. There is sufficient capillary moisture in very fine sands, silts and silty clays to develop detrimental frost heaving during freezing weather. In the past various maintenance engineers have tried to correct these frost heave areas in the above mentioned materials by the installation of drains (either tile or stone bleeders) and were not successful. The reason for this is that capillary moisture cannot be removed by drainage. Thus the elimination of detrimental frost action in these soils must be accomplished by the removal of the objectionable material the width of the road surface, the depth of three feet and backfilling with drainable material, care being taken to provide drainage to the excavated area; or by the raising of the grade at least three feet over the objectionable materials. To date we have been successful in eliminating detrimental frost action in the subgrade by these corrective measures.

Some recent work to eliminate frost action in highly capillary soils by the introduction of chemicals to lower the freezing point, thus preventing the freezing of the void water, has been tried and in some cases this seems to be very effective. There is, however, in my mind some question as to whether such treatment of objectionable soils under new concrete pavement would be desirable, since both sodium and calcium chloride may cause additional damage to the concrete due to the crystallization of these salts in the concrete. Considerable work has been done in connection with the action of chlorides on concrete and has been published in the Proceedings of the Eleventh Highway Research Board.

It might also be of interest to state that we have been trying to eliminate detrimental frost action by the mixing of various soil textures in order to improve their internal drainage characteristics. In certain areas we frequently have encountered small areas of silt and sand, or perhaps gravel, too close together to economically excavate. Therefore, by means of Le Tourneau graders, or other suitable grading equipment, the questionable area can be excavated in layers to the recommended depth and placed at one end of the excavation. This procedure uniformly incorporates the silt, sand and gravel into a synthetic mixture which has desirable drainage characteristics. The mixed soils are then placed back into the excavation and with the addition of suitable drainage structures the questionable frost heave areas have been corrected.

Prof. Lang: As I recall, Mr. Stoddard in his paper says something about it.

Mr. Stoddard:
Iowa

The Iowa Highway Department has done some frost boil work. In the parts of the road which had previously given trouble with maintenance when the surface was gravelled, these places were treated by excavation of the subgrade and filling in with more stable material. Judging from the experience Minnesota has had, my observation is that it has been necessary to extend the treatments each year. We borrowed this method of treatment from Minnesota. It appears to me that that type of stabilization is absolutely dependent upon the drainage of the frost layer. In a good many cases, you can be sure that drainage will act as a reservoir to supply water to unstable soils beyond the extent of the treatment and thereby extend the area of failure.

Prof. Lang: Has anyone present anything further to offer on this subject?

Mr. Olmstead: Michigan

I might state that the policy of the Michigan State Highway Department for the past ten years has been to maintain a staff of soil engineers who are trained to identify as well as suggest corrective measures for various subgrade conditions which are apt to cause failure of road surfaces.

The nature of their field work is to make preliminary soil surveys which consist of location of frost heave areas, sounding muck or peat swamps, detecting areas of excessive internal seepage, and location of suitable borrow materials. This information is turned over to the Road Design Department which makes recommendations for correcting the undesirable features revealed by the preliminary soil studies of the soil engineers. This advance information also enables corrective measures for questionable subgrade conditions to be specified at the time of the initial bidding of the grading contracts. Thus, the close cooperation which exists between the soil engineers, the laboratory and the design department has been very successful in reducing the premature failure of new road surfaces in our state.

Prof. Lang: In closing, I might say that it is only a matter of time until the various highway departments will have larger and more efficient soil organizations. The bituminous surfacing is dependent upon subgrade support, and the entire length of a road is frequently impassable or uncomfortable due to bad soil conditions on some sections.

Prof. Duff:
Nebraska

If I may I would like to add a few more words to the discussion on the previous subject of improving the density and stability of the natural soils during the process of grading. I probably should have spoken on this subject when the opportunity was offered, but I did not expect a change in subjects so quickly.

Nebraska has specified the density to which soils should be compacted on a number of approach fills in connection with overhead crossings that are being constructed. The Proctor method of compaction was utilized in this work and where the moisture content of the fill material was not sufficient to produce the required density it was necessary to either add water directly to the fill material as it was being placed or to add the water to the borrow pit. Samples of soil from the borrow pits to be used were sent to the testing laboratory for analysis where the per cent moisture required to produce maximum density was determined.

The specifications for this required a compaction to 90 per cent of maximum density with a specified permissable plus or minus variation in moisture from the amount of water that is required to produce maximum density. Where fills are constructed by this method they are found to be practically free from settlement and are much more resistant to displacement by the natural weathering elements. While this type of construction has been limited thus far to high fills in connection with grade separations and the backfilling of channel changes, I believe it is only a matter of time until it will be used to some extent on all grading operations.

In connection with the determination of the density obtained on compacted fills we have developed a special soil bit for obtaining undisturbed samples. This soil bit is four inches in diameter and is made of very thin seamless steel tubing. The cutting edge of the bit is rolled in with a slight taper on the end so that the sample obtained is slightly smaller in diameter than the actual diameter of the tube. This permits the soil core to be easily removed from the tube by unscrewing the bit from the driving head.

The tube was formerly about 15 inches in length and was forced into the soil by means of auxiliary anchors and a jack. In the type now used the tube is about seven inches long and is driven into the soil and samples taken in six-inch lifts. The fills are usually checked as they are being constructed, but this bit has also been used to obtain cores to check the density of fills previously constructed to depths of as much as 15 to 20 feet.

Two methods are used for determining the density of the soil cores. The preferable method is to weigh the core as soon as it is removed from the bit and then dip it in liquid paraffin. By reweighing in air the volume of paraffin added is easily calculated, after which its density can be obtained by weighing in water. One advantage of this method is that after the density has been obtained a sample can be taken from the core to determine its moisture.

The other method used is to weigh the core and then soak it in kerosene, after which it is reweighed while immersed in kerosene. To obtain the moisture content when this method is used it is necessary to retain part of the core before it has been weighed and placed in the kerosene. This is a very quick method if only the density is required.

Prof. Lang: I think we will now proceed to a discussion of the next paper, "Fundamentals of Gravel Base Construction," A. E. Stoddard, author.

Prof. Duff:
Nebraska

I should like to ask Mr. Stoddard a question. Have you ever used a machine for mixing the aggregate of the stabilized base?

Mr. Stoddard:
Iowa

Well, on state highway work we have not. The city of Ames built, last year, a small job about three miles long in which they used plant mixture on secondary city streets. Of course they avoided the trouble of drying and pulverizing the binder in road mix which is very objectionable in city work because of dust. The mixture was made by combining the aggregates with clay which was obtained dried and pulverized from a commercial brick and tile plant. This method worked out very well. The mixing was performed in an ordinary concrete mixer and produced a fairly good mixture.

I was wondering whether or not any state has had any experience with the Pioneer Mixers, where they add water and clay in the mixing process. I understand some machines are being made for that purpose.

Mr. Reagel:
Missouri

We have had a bituminous job on which we have used a Barber-Green Pugmill in mixing. This machine mixes the aggregate with water and bitumen and deposits the material in a windrow.

Prof. Duff:
Nebraska

Were you able to add sufficient water to obtain a finished mixture with one passage of the machine or was it necessary for the material to go through the machine twice or oftener?

Mr. Reagel:
Missouri

We were able to do it in one mix. In the case of dry material in the summer time it requires around 40 gallons of water to the cubic yard of aggregate plus oil to permit discharging from the machine.

Mr. Nevitt:
Socony-Vacuum
Missouri

Mr. Stoddard discussed formulas and methods for determining the proper thickness of base but gives no final opinion. I would like to have his conclusions and recommendations.

Mr. Stoddard: Iowa

I am not at all sure that I have reached a conclusion. In the first place some preliminary tests which we have made on this stabilized mixture indicate that the material has considerable strength in transverse bending.

In checking the moisture content of surfaces built two years ago, we find that actually the moisture content of the stabilized mixture is less than half of the moisture content of subgrade soil at that time. Just how much we can depend on this low moisture content we do not yet know.

In regard to Mr. Gray's formula it is apparently fairly reasonable, with the exception that I do not believe that you can depend on the bearing pressure of subgrade being uniform over the bearing area. In your paper this morning you mentioned Mr. Older's formula for pavement strength. I believe that most engineers in designing concrete pavement depend on Mr. Westergaard's formula which takes into consideration the bearing power of the subgrade. In this formula the subgrade support or reaction is proportional to the deflection of the pavement. The amount of deformation of the subgrade is determined by shape of the deflection curve. After we have a definite deflection curve for bituminous surfaces we can determine the amount of subgrade reaction and the bearing power required.

On the Bates Experimental Road, twelve to fourteen years ago, Mr. Hogentogler of the Bureau of Public Roads made loading tests and measured deflection of various types of pavement slabs. He also measured the intensity of subgrade pressure by use of Goldbeck Pressure Cells. We were not able to find that the area of distribution of wheel loads through bituminous surface, consisting of 3-inch Topeka mix on 12-inch macadam, exceeded the direct pressure which would be transmitted through the base at an angle of 45 degrees. We were unable from deflection measurements to note any considerable distribution of the load. These surfaces were on an ordinary macadam base. It is possible that your stabilized soils, which have a more adhesive binder, would give more strength in flexure than macadam base. Until we know more about the transverse strength of stabilized mixes, we do not have any definite conclusions as to what should be done.

Mr. Nevitt:
Socony-Vacuum

For example, you say that the bearing power is not uniform, and I agree with you. At the same time you might define your uniform bearing power as the average under the circle of your cut. In other words, you might work out a system of measurement or a correlation between measurement and application which takes care of your average. Working things back toward your known loads, the error, so to speak, cancels out.

Mr. Stoddard:
Iowa

That is true to a certain extent. If the assumed unit of safe bearing power were low enough, there would be little error in assuming a uniform pressure.

Mr. Nevitt:
Socony-Vacuum

I don't really like to say too much. I am very interested in this type of thing without knowing much about it. In Mr. Gray's formula he assumes a 45 degree angle and Mr. Stoddard questions this, and I check the question as being logical. It does seem to me another variation could be introduced. It might be possible to tie up stability of the material as shown by the Hubbard field test or the California stabilometer test with that angle. In other words, introduce into the formula another factor, it taking a 45 degree angle.

Mr. Kirby:
Utah

I should like to ask that a nomenclature be changed. You refer to pressure still asphalts as cracked asphalts. I think that they should be referred to as pressure still asphalts.

Prof. Lang: What would be your purpose in doing that?

Mr. Kirby:
Utah
I think the statement that they are cracked asphalts is incorrect. They are asphalts produced by cracking and chemically there is a vast difference.

Prof. Lang: Essentially what do you mean?

Mr. Kirby:
Utah
The very word "cracking" means disintegration.

Prof. Lang: How would the spot test effect you with these names. Would that be a differentiation?

Mr. Kirby:
Utah
The spot test has no particular bearing on this particular statement that I made. Asphalts produced by cracking as far as I know have a poor spot test.

Mr. Stoddard:
Iowa
There would be no limit to the number of classes of partly cracked and uncracked oils.

Mr. Kirby:
Utah
I would say that you would only have two asphalts, or probably in that particular category I refer to, you would have asphalts from pressure stills and those made directly from crude. Cracked asphalts is chemically an incorrect term, I would think. What would you think Dr. Loy, Mr. Ramey?

Mr. Kushing:
Michigan
How would it make the material any better?

Mr. Kirby:
Utah
Pressure still asphalt is an old material. It is my honest opinion that it should be properly designated.

Prof. Lang: Any other discussion of this paper? The next paper for discussion is on the "Quantity of Liquid Asphaltic Material in Dense Graded Mixtures," by C. F. Ramey.

Mr. Benedict: B. P. R.

A short while ago the New Mexico formula for determining the required percentage of bituminous material in a mixture was shown on a lantern slide. Without intent to discredit the adequacy of this formula I should like to inquire why the factor of 1.25 or 1.50 times the amount of slow curing liquid asphalts is applied when cutback asphalts are used. It has been our experience that the same amounts of each are usually required. and this is borne out by the statement of Mr. Hubbard of the Asphalt Institute to the effect that the residue from distillation at 680 degrees F. represents approximately the amount of residual asphalt after a year's service. On this basis the same quantities of SC-2 or MC-2 would be required. Therefore, I question whether or not an aggregate will demand more cutback asphalt than road oil, as the former is the more cohesive of the two.

Prof. Lang:

It is generally considered advisable from the standpoint of permanence to use the maximum amount of bitumen possible and still have a stable surface during hot periods. Because of its higher cohesive strength more cutback asphalt than road oil can be used. However, the evaporation loss in cutbacks is higher than on road oil.

Mr. Nevitt: Socony-Vacuum

Mr. Benedict, was there not in a recent issue of "Public Roads" an article showing that the maximum stability, and optimum asphalt content from that standpoint, increased as the consistency of the asphalt increased, so that the residue from a cutback would show a higher cohesion than an SC product? In other words, the variation of stability with asphalt content was brought out, in which it showed that both the stability and the maximum allowable content both increased as the consistency of the material increased.

Mr. Benedict:
B. P. R.

I agree that Mr. Nevitt's statement concerning the "Public Roads" article is correct. I had hoped to arouse by my former remarks a discussion concerning the necessity for removal of most of the solvent from kerosene cutback bituminous mixtures of aeration, particularly when the MC-2 or MC-3 grades are used. It is my opinion that it is essential to the durability of the mat that this be done, but many engineers do not agree.

Prof. Lang:

Are there any more discussions?

Mr. Powers:
Arizona

In that connection the state which I happen to represent has used both types of material, SC-2 and MC-4. We have laid both types by vigorous aeration either during road mix or after plant mix operations and so far as we can see there is no difference in results. We have also laid MC-4 after plant mixing with little or no aeration and the results have been satisfactory.

In connection with MC-5, our policy has been to lay down without any aeration, although it has been laid in comparatively thin sections not to exceed ½″ to ¾″. No aeration is necessary and the results obtained have been satisfactory.

Mr. Duff:
Nebraska

Our experience has been the opposite and we find that aeration is very necessary where MC-2 and MC-3 products are used and I would like to take that position on the question. Last year we were using cutbacks almost exclusively. On one project the contractor was successful in convincing the project engineer that he could produce a much smoother surface if he was not required to do so much aerating. This was correct insofar as appearance was concerned at that time. The project went through the winter in very good shape as it was a late job and experienced no hot weather after being laid. About the first of May it began to soften up and by the first of June it was necessary for the state, at considerable expense, to completely remix and aerate the mat in order to obtain a more stable mixture that would offer greater resistance to displacement by traffic and have greater load carrying capacity. This year all contractors are being required to thoroughly aerate the bituminous mix before they are permitted to lay it. Some contractors object to thorough aeration on account of the extra manipulation at the time of construction involved but it is better for the state to pay for the aeration at the time of construction rather than tearing up and aerating the mat six months later at an extra cost. On one job this year a contractor insisted that the bituminous mixture was sufficiently aerated while the engineer of bituminous construction was equally sure that it was not. Samples of this bituminous material were submitted to the laboratory for a decision. Stability tests were made at room temperature on the material as received and after it had been heated for 24 hours in an electric oven maintained at 140 degrees F. and then allowed to cool to room temperature. The stability was increased 100 per cent by this process, which clearly indicated insufficient aeration and had the bituminous mixture been laid down without further aeration, the mat would no doubt have rutted and produced an unsatisfactory riding surface which would not have offered sufficient resistance to displacement by traffic.

Mr. Powers:
Arizona

How much was the evaporation loss after the samples were put in the oven?

Prof. Duff:
Nebraska

Not more than 6 to 8 percent based on the oil content of the mixture. I am speaking of an MC-2 cutback. We are using MC-2 and MC-3 cutback almost exclusively this year. There was no question about the stability being increased by additional aerating as the samples sent in from the field after the bituminous mix had received additional aeration were in line with the results previously obtained in the laboratory.

Mr. Groves: North Dakota

We have had about the same experience in Nebraska. This season we laid some MC-3 just before a spell of hot weather. Two weeks later it became so spongy that it was necessary to tear up the mat and aerate the mix. We have quit using MC-3 and are going to use MC-4 in order to avoid this softening of the mat. This softening of the mat is probably due to the large quantity of kerosene retained in the mix. We believe that it is preferable to get the kerosene out of the mix before laying.

Mr. Kushing: Michigan

There does not seem to be any place in this part of the meeting for the question I want to ask. However, it is very pertinent to me. In Michigan, there is being built this year, 260 miles of oil aggregate roads. The question is, what kind of oil shall we use? Shall we use slow curing or medium curing oils? We have had a great deal of trouble with cutback. We want to use slow curing oils and they tell us we are going backward. All of the western states are going to MC oils. I don't know what is causing this change to the MC grade. As far as we are concerned, we get better results with SC than with MC oils. With those preliminary remarks I thought perhaps that there might be someone in the group who would discuss it. I have never heard it discussed and should like to hear it.

Prof. Lang:

I shall refer that question to the Conference Board.

Mr. Powers: Arizona

I will give you the reasons the Arizona Highway Department believe the medium curing asphalts are better than the slow curing types. The usual experience is that SC is very susceptible to being displaced by water. More so if the material has more preference for water than it does for oil. In any gravel pit we have to take the materials as they come. Failure from use of lighter types of oil (SC types) may occur because in order to get proper set it is necessary to raise the percentage passing the 200 mesh, somewhere about 5. Ordinarily from 5 to 7½. When you do that you introduce the material that causes you the most trouble.

MC type oil, on the other hand, because of its ability to harden—manufactured from a different product, you get away from the addition of 200 mesh. Eliminate it since it isn't needed to harden the mix and consequently you have in that type of material a better probability of success in building an oiled road.

Prof. Lang: The paper on "Mineral Aggregate for Dense Graded Bituminous Mixtures," by Mr. J. W. Kushing is now open for discussion.

I might say that this is a very comprehensive paper on the subject. I am very sorry that there is so little time left for discussion.

Mr. Kushing:
Michigan

The only thing that I would like to emphasize particularly, in regards to the specification limits, is the point that we bring out in our conclusions, which is: In the setting up of specifications there are certain economic factors which must be considered, and they depend entirely upon the cost, quality, durability and availability of the material. It is assumed that the results obtained by the various states are satisfactory. We had to make that assumption. If there is a variance in opinion, it is probably due to the fact that different emphasis has been placed upon one of the above economic factors. General cognizance of the principles regarding aggregate which have been covered in this paper will aid in successful results, but it does not necessarily hold that specifications used in one locality will guarantee satisfactory results in another.

Prof. Lang: The final paper in this group is "Mixing of Aggregates and Bitumens," by Mr. Levi Muir.

I do not think that we want to go into any of the construction phases tonight, as "Construction" will be discussed tomorrow.

Is there anything you wish to say, Mr. Muir?

Mr. Muir: Utah

When I was asked to discuss the subject of uniform thickness of oil films by Chairman Lang, I found a report by Bennett and Gillies of the California Highway Department covering this subject where D grade asphalt was used as binder. The method makes use of a stain test. The material on which the stain is to be checked is heated to 200 degrees F. and compressed in a 2-inch cylinderical mould under a pressure of 6000 lbs. per square inch. About 20 thicknesses of filter paper is placed between the mixture and the plunger. Free oil on the surface of the aggregate is forced through the filter paper. The number of papers stained is a measure of the oil film thickness. There was a direct relation between stain numbers and Hubbard and Field stabilities. The oil Ratio-Stain curve ran rather flat until a certain oil ration was reached. Any addition of oil after this point is reached causes the curve to rise very abruptly. Maximum stability is found at the point where the curve breaks. Additional oil causes the stability to decrease abruptly.

Prof. Lang: I will now turn the meeting back to Mr. McKinnon.

Mr. McKinnon: As that concludes the discussion of "Developments and Fundamentals," the meeting stands adjourned.

SECTION III.

PAPERS PREPARED ON, DEVELOPMENTS IN PRACTICAL DESIGN AND CONSTRUCTION OF BITUMINOUS SURFACES and the ANALYSIS AND REVIEW OF THESE PAPERS AS PRESENTED AT THE CONFERENCE BY THE CHAIRMAN OF THIS SECTION.

RECENT DEVELOPMENTS IN DESIGN AND CONSTRUCTION PROCEDURE IN BASE COURSES AND IN DENSE GRADED BITUMINOUS MIXED SURFACING IN THE NORTHWEST

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Base Courses

A scrutiny of recent developments in design and construction procedure in base courses in the Northwest impresses one with the often stated fact that the most successful principles evolve from the need for adequate drainage. By this is meant not only the well-established practice of draining the subgrade by generous use of culverts and deep side ditches, but also provision for drainage within the soil portion of the base course itself, as well as for protection against the capacity rise of water from the subgrade.

Need for the development of knowledge of the relation of soil properties to the stability of highway foundations and to the durability of their wearing surfaces has been recognized for some time, but until recent years studies leading to a solution of these problems have lagged behind the construction of highways. Even now the development of the application to highway construction problems of the physical and chemical behavior of soils under varying conditions presents probably one of the most undeveloped and yet most fruitful fields of highway engineering knowledge. However, progress of practical value is constantly being made; for example, there is R. R. Proctor's method of embankment compaction, which is obviously a matter of first importance in any type of surfacing construction. His principle of "optimum" moisture content and the apparatus developed by him to test the degree of compaction are being used in a modified form in California, but have not as yet been adopted in the Northwest. The method is not as universally adaptable here as in the Central States, where it appears to be the most popular, because much of our soil contains rock or gravel and because often our grading is carried on during the winter months when the natural moisture content of the soil is beyond the "optimum." Yet it appears applicable to sufficient of our projects to merit its adoption.

The Oregon and Washington highway departments have installed laboratory equipment for determination of the soil constants in accordance with the A. A. S. H. O. method and are establishing the practice of designing the soil portion of base courses accordingly. District One of the Bureau of Public Roads (Montana, Oregon and Washington comprise District One's territory) recently has applied in addition the soil profile scheme to some of its forest and national park highway designs.

We have this progress in soil analysis to thank for most of the recent improvements in base course construction specifications. Low cost crusher run products and run-of-bank materials falling within certain size limits have been popular for several years in the West for use in building up unfavorable subgrades. They were, and still are to a great extent, employed with "rule of thumb" methods, but at the same time it must be acknowledged that these methods were based upon many years of experience with both the underlying foundation soil and the material used for building up its traffic-supporting power. With the information given us by the recently developed soil tests, we are now able to select base course surfacing materials more intelligently, determine more definitely the quantities to be used under different subgrade conditions and write accurate, enforceable specifications for our contractors. The soil profile showing the subgrade conditions is not expected to give a mathematical answer concerning the depths of surfacing material required, but offers a greater degree of accuracy of information than any method previously employed.

In the Northwest the selection of the type of base course does not depend upon the type of bituminous surfacing to follow, and it appears to the writer that this policy is thoroughly sound. All bases must be heavy enough to distribute the wheel loads sufficiently to avoid overtaxing the bearing power of the subgrade soil when in its weakest condition. Capillarity through the base course must be controlled to prevent instability of the course itself or destruction of the bituminous surfacing. Through either a mechanical interlocking of clean, sharp stones supplemented by keying and filling with stone chips and screenings or through a firm embedment of the coarser stones in properly selected fines, the base course must be tight enough and stable enough to resist internal movement under traffic. Oregon's design in particular is based upon the proposition that no bituminous surfacing will endure if it is continually subject to flexing and distortion by a yielding base.

Suitable run-of-bank gravel is available in many vicinities in the Northwest at low cost. Logical construction dictates the use of this material in the nature of a subgrade reinforcement, the amount depending upon the supporting power of the subgrade soil with the general rule of "when in doubt add more." Natural material, if not too large, is applied as encountered; otherwise, it is crushed or screened to a maximum size of 3″ or 4″. This subgrade reinforcement costs in place an average of $0.75 per cubic yard, or $0.025 per square yard inch, compacted, and forms the body of the base course. Over this we specify an adequate thickness, usually about 3″ loose measure, of a crusher run product of 1½″ maximum size for a leveling course, followed by a 2″ smoothing layer of fine crushed gravel or stone ranging from ¾″ to dust. The latter two courses cost an average of $1.50 per cubic yard, or $0.05 per square yard inch, compacted. This type of surfacing, which is placed over the full width of the roadbed to assure adequate drainage and to permit emergency use of the shoulders by traffic, must be followed immediately by a bituminous course to avoid dislodgment by traffic, as the fines used are not of a cohesive quality.

Where the only local material available possesses fine aggregate of a quality unsuitable for base course construction of the type described, we specify removal of the fines and production of a suitably graded product through crushing clean gravel or rock. Also, under these conditions we frequently employ a modified waterbound macadam procedure, using crushed ledge rock or crushed boulders dry-keyed with suitably sized crushed stone and filled with stone screenings, followed by watering. This construction, while more costly than the run-of-bank or crusher run types, is less conducive of capillarity and possesses greater stability. The practice of "ballasting" the subgrade with a heavy course of suitable gravel to distribute the load and topping this with a 4″ thickness of keyed macadam to supply definite rigidity under the bituminous surfacing, while not a recent development, has much to recommend it.

California is making extensive use of a "slurry" base. This consists essentially of a dense graded aggregate, usually of 2½″ maximum size, pre-mixed with water and spread on the roadbed, followed immediately by smoothing and rolling. The design of the mixture is such that the coarse aggregate is suspended in a sand-clay mortar of sufficient cohesiveness to furnish stability yet without appreciable swelling and shrinking action under alternate wetting and drying. The average mixture contains about 15% clay, and might be termed a "mud concrete." Only sufficient water is added to cause the sand-clay mortar to tighten, giving a crumbly rather than a sloppy appearance when spread. The aggregates, which are usually run-of-bank or screened gravel blended with suitable field clay or loam, are separated into two sizes on the ¼″ sieve, recombined by weight and mixed with water in a pug-mill or rotary drum type mixer. If the subgrade is particularly unstable, emulsified asphalt of the type commonly used for soil stabilization work or sometimes standard mixing emulsion further thinned with water, is added to the mixture to preserve it. Pull-type boxes are used for spreading on the road, followed immediately by blade smoothing and by rolling. An 8″ depth is usually used, the cost averaging $2.25 per cubic yard, or $0.075 per square inch, compacted, for the non-bituminized "slurry" base, with $1.50 per cubic yard additional for the emulsified asphalt stabilized mixture.

As has been stated, in the Northwest the determination of the depths of base to be used on the various soils rested with the engineer's best judgment, reinforced by a practical knowledge gained through experience with pavement behavior on similar soil. Generally, our practical judgment has not been far out of line with present day technical soil practice. We have found that types A-1, A-2 and A-3 soils, which are in themselves good foundation materials with low capillarity, require only thin layers of surfacing material; it is possible that full advantage has not always been taken of this fact. Here a pre-determination of the foundation soil characteristics stands the engineer in good stead, not so much for the prevention of failures as for a saving in cost, as many A-1, A-2 and A-3 soils will support a bituminous surfacing under moderately heavy traffic without any surfacing material other than that required to smooth the foundation.

The A-4 and A-5 soils, which are composed of silt of varying degrees of elasticity, are moderately high in capillarity and become quite unstable when wet. These can often be drained by deep, wide ditches, but even with this drainage it is wise to plan on a moderately heavy base course. Our designs have ordinarily provided for 8″ total compacted depth of surfacing on soils of these types.

The A-6, A-7 and A-8 soils are highly capillary, usually spongy clays and peats which are very unstable when wet. Over these a heavy base course surfacing, 12 inches or more in thickness, has been provided, as practical experience has demonstrated that less depth would mean many failures and heavy maintenance costs. If there was any doubt as to the ability of the available run-of-bank or crusher run types of surfacing to cut off the capillarity, the additional expense of the modified water-bound macadam type was considered justified.

It has been our experience that the clay soils when wet and unstable will sometimes gradually absorb the base course into the subgrade. This is particularly true in localities subject to recurrent freezing and thawing. Evidence has been found of surfacing materials being drawn into the foundation as much as two feet below their original position, with consequent failure to support the traffic loads. The only solution to this problem that the writer can suggest, aside from bituminous stabilization, is to "blanket" clay subgrades with sand or rock screenings before the surface is placed.

Now that we have examined in a general way how the Northwest states are solving the problem of the selection of a base course surfacing, we shall consider the types of material accepted for base course surfacing and those that are rejected. While good materials are ordinarily procurable here, the general problem merits some discussion. With the modern prevalence of bituminous construction it is no longer necessary to limit the Deval abrasion and hardness characteristics of surfacing rock to those once required to resist breakage under steel-tired wheels and abrasive wear of the loose stones as they were ground together under traffic; but new requirements for the quality of the aggregate fines have become necessary.

Obviously, the function of the base course is to make the necessary distribution of the traffic loads over the subgrade. Therefore, a material must be selected that will service in its design capacity under all conditions of moisture that may be contemplated. It has been quite definitely established that the control of two certain characteritics, capillarity and cohesiveness, or plasticity, is of paramount importance in determining the ability of the soil portion of a surfacing to function as it is intended. The maximum capillarity of all soils is indicated by the liquid limit test, which is the maximum moisture content when in the plastic state. At the liquid limit the cohesion is practically equal to zero. A qualitative measure of the cohesive property of the soil is furnished by the plasticity index test, which is the difference between the plastic limit and the liquid limit and is an expression of the range of moisture contents through which plastic soils remain plastic and consequently cohesive. The liquid limits and placticity indices for sand materials are low, while those for objectionable clay materials are high, thus these tests indicate relative clay content and warn the user against the tendency of some clays when moist to become a lubricant instead of a stabilizer. For the soil portion of a surfacing course, the liquid limit should be limited to 25 and the plasticity index to 6, except possibly in extremely arid sections.

We seldom find it necessary to use a binder if the surfacing material is suitably graded when produced. When used, binder is selected of such quality and grading that when blended with the finer portions of material already existent in the surfacing it forms a product falling within the quality limits desired. With a sandy, extremely granular surfacing product the binder, used in limited amounts, is sometimes a clay in the A-7 classification, while at the other extreme a surfacing containing fines of a too clayey nature is made usable by the addition, under the classification of binder, of sandy, granular particles. In other words, the function of the binder has become more one of bringing the characteristics of the soil portion of the surfacing to within those defined for the A-3 group than of actually binding, as the term implies.

There is sometimes a misconception of the certainty of the quality of fine material obtained by crushing rock or gravel particles; this cannot be taken for granted, although ordinarily no difficulty will arise on this score. Since all soil, whether clay, silt, sand or mixtures of these, comes from a parent rock, the operation of crushing is but an accelerated erosion and breakage which, in nature's slow way, created them. Consequently we subject the fines produced by crushing to the same careful scrutiny as we do those existent in the natural deposits.

Stage Construction

To conserve the base course material, test the adequacy of the foundation construction when surface evaporation is cut off, and in the interim to provide the dustless surface demanded by modern traffic without jeapordizing a relatively costly bituminous surfacing, it is the general practice of District One of the Bureau and most of the Northwest states to apply, as the first step in a stage construction plant, a low cost bituminous surface treatment as soon as the placing of the untreated surfacing has been completed. As this is regarded essentially as a proving course, it is ordinarily designed to a cost as low as is practicable. There is a temptation to introduce refinements and betterments into this treatment, each one, of course, adding to the cost. The total effect of such betterments may be to bring the cost and result up to those of any other semi-permanent type necessary to provide an adequate surface for light traffic roads on good subgrades, but really outside of the type discussed herein as stage construction. Oregon uses a relatively thin treatment constructed in two courses by the penetration method, the second course of stone being of a size that will key the first and followed by a seal coat. The completed bituminous mat is approximately three-fourths of an inch thick and costs, including shaping of the roadbed but not watering or compacting of the surface material, $1,500 per mile for a 20′ width.

In their stage construction procedure Montana, Washington and District One of the Bureau utilize a bituminous surface treatment consisting of a double application of 0.3 gallon per square yard each of bituminous prime material, a six- to ten-day curing interval being allowed between the applications. Each is covered with stone windrowed during the shaping operations, the first being permitted to penetrate the surface before being covered and the second being covered immediately and usually rolled to embed the cover material uniformly. Usually it is necessary that the road be kept open for traffic; if not, the prime coat cover is omitted.

For the bituminous surface treatment described we have found MC-1 and MC-2 liquid asphalts very suitable for the first or penetrating application, the MC-1 being best for use on a tight, well bonded base course and the MC-2 being best for one that is less perfectly compacted. MC-2 and MC-5 are excellent materials for the second application, the former being preferred where the windrow of cover aggregate contains a considerable amount of fines and the latter where the cover is practically clean stones. When the treatment is applied in conjunction with the surfacing contract, thereby avoiding duplication of shaping the roadbed and shoulders, the completed treatment, exclusive of watering and compacting the untreated surfacing, costs about $800 per mile for a 20-foot width and results in a bituminized mat about one inch thick. We find that this will carry moderate traffic for two or three years; by the end of that time weak spots have been discovered and corrected under maintenance and we have an excellent tested base for a super-imposed bituminous surfacing. On some projects we have extended the treatment to the full width of the surfaced roadbed and find that this practice greatly facilitates maintenance.

Dense Graded Mixed Surfacing

When a dense graded bituminous surfacing of the plant mixed type is to be placed upon an untreated roadbed, the use of a bituminous prime coat similar to that just described has been found advantageous, as it seals the roadbed surface to some extent from the entrance of moisture and also provides a suitable floor for the hauling and spreading operations. We have found a prime coat to be of equal value in road mixed construction where conditions are such that it can be applied satisfactorily. However, much of the prime coat is often lost where no detours are available and the aggregate is already in place on the road, as the windrow occupies a portion of the roadbed, making it necessary on the narrower roads to carry traffic too soon over the freshly applied prime material.

For bituminous mixed surfacings on narrow roadbeds, we have found that a thickened edge design assists in counteracting the edge failures that result from wheel leads near the outside of the mat. Ordinarily, however, we prefer to avoid edge failures by adding to the width of the bituminous surfacing, particularly since the cutting of the trench for the thickened edges results in partial destruction of a previous bituminous treatment.

Aggregate for dense graded road mixed and plant mixed surfacings must be hard and durable enough to carry the loads to which they will be subjected. Nevertheless, rock may be used that is too soft for penetration macadam construction, since in the dense graded mixed types the stone particles are cushioned by the bituminous mortar. This does not mean that the hardness and durability of the aggregate are or should be disregarded. For determining the susceptibility of the aggregate to breaking down under traffic, Washington and California are making extensive use of the circular track test first described by A. T. Goldbeck in the 1934 Proceedings of the American Society for Testing Materials and of the Los Angeles rattler test. Supplementing this, they use also a "breakage factor" test which is popular in Oregon as well. This latter test consists essentially of subjecting a sample of clean, coarse aggregate of prescribed grading to a definite compression load followed by rescreening, the breakage factor being computed from the increases in amounts passing the various sieves and indicating the resistance of the stone to withstand crushing by traffic or by construction rolling.

The fine constituents of the aggregate for bituminous surfacing must be examined carefully for their detrimental tendency to swell, become unstable, or lose their coating of bituminous material when in the presence of moisture. Fine aggregate when suitable will possess a liquid limit not in excess of 30 and a plasticity index of not in excess of 8, or preferably less, but further tests are necessary. To determine the relative affinity of the dust portion for water as opposed to that for the bituminous material the Asphalt-Water Preferential, or Demulsibility Test originated by J. W. Powers is used throughout the Northwest as well as in California. Of similar popularity is the Swell Test, also originated by Powers, to detect detrimental swelling of the total aggregate when compacted bituminous dense graded mixture is soaked in water. In addition, District One of the Bureau recently has been breaking up the Swell Test specimen into pieces of one-half cubic inch to one cubic inch in volume, and immersing the pieces in water at room temperature for 24 hours and stirring, the criterion of the suitability of the material being its resistance to loss of the bituminous coating. The Bureau has also recently been using a rock coating test which consists of simply coating pieces of coarse aggregate with the bituminous material proposed for use, soaking these in water at a temperature of 140 degrees F. for 24 hours, and observing the tendency of the bituminous material to slough off.

District One of the Bureau has experimented with, but has not yet adopted, still another method of testing for hydrophilic properties in bituminous mixture. This method, which Victor Nicholson called attention to in a report published in the 1936 Proceedings of the Association of Asphalt Paving Technologists, consists essentially of kneading water into a bituminous mixture to determine whether or not the water will displace the bituminous material. As Mr. Nicholson points out, this test is especially interesting because it simulates the action of water in the mixture on the road under traffic and can be easily performed in the field. However, it does not appear well adapted for use with mixtures containing heavy asphalts.

There have been no recent marked developments in either design or construction procedure of road mixed bituminous surfacing in the Northwest. New road mixing machines, as substitutes for mixing by blades, have appeared on the market, but these have not been substantially different from those in use for some time. RC-3 liquid asphalt has been used successfully in Oregon for the past four years for road mixes, but is employed with the realization that the grading of aggregate must be suitable; that is, the dust content must not be disproportionately high for the intermediate sizes, thus causing "balling" through a rapid combination of the bituminous material and the dust. The contractor must expect to provide sufficient equipment to complete the mixing and spreading during the same day, as the solvent in the RC-3 evaporates too rapidly to keep the mixture workable for a longer period.

During the past two years Montana, Washington and District One of the Bureau have swung to the use of MC-2 liquid asphalt for road mixing purposes. This material, having a kerosene solvent and consequently permitting a longer mixing period, is more adaptable to varying conditions than is the RC-3. While the residual asphalt is probably not as hard, the MC-2 mixes have proven themselves firm and durable under traffic. We are convinced that to obtain maximum stability with aggregates possessing a moderate amount of dust, say 5% to 10% through the 200-mesh sieve, the MC-2 mixes must be aerated to reduce to a minimum the amount of solvent before the mixture is spread and rolled. For determining the solvent content Bureau District One uses a field distillation apparatus heated by a gasoline stove and does not permit spreading until the percentage distilled off, as compared with the quantity of cutback asphalt in the sample, is below 8. If the contractor opens up sections long enough that two days elapse between the time the MC-2 is applied and the time the mixing is complete, the solvent content has usually been reduced to the desired maximum.

For dense graded plant mixed bituminous surfacing, we have drawn away entirely from the use of slow curing liquid asphalts. RC-3 has been used successfully on a considerable mileage of both State and Bureau construction in the Northwest. We have not attempted to use the medium curing cutbacks in plant mixes because of the difficulty and expense incidental to proper aeration.

A recent development in equipment for spreading dense graded bituminous plant mixtures may modify the entire design of this type. The equipment referred to is a self-powered, mechanical spreading and finishing machine which utilizes a floating, saw-tooth edged screed. One type screed is oscillating and is controlled and supported by equalizing side runners 18 feet long, while the other type is horizontally reciprocating and the screed supports are built into the machine and the screed height is controlled largely from the rear wheels, which run on the smoothed bituminous mixture just placed. The most advanced machines have a revolving blade-equipped agitator just above the screed to assure a uniform flow of material from the spreader's supply hopper. Truck loads of the bituminous mixtures are fed into the hoppers of the machines which move forward smoothly under their own power, pushing the truck ahead of them until the load has been emptied. The hoppers do not carry the full capacity of the larger trucks but are intended only to absorb the differences in flow from the truck and to supply storage to maintain operation between truck deliveries. The machines leave a smooth, uniform ribbon of bituminous mix behind them, which needs no further smoothing before being compacted by rolling.

During the past season many Northwestern contractors elected to use the self-powered paver type spreading machines in preference to the customary blade spreads even though the specifications required only the latter. This indicates that if we specify these machines no increase in bid prices will be reflected. There is no question but that the uniformity of texture is superior to that of the blade-spread bituminous surfacing, as the machines are so designed that segregation of material does not take place. In fact, their principle of operation is the same as that of the mechanical pavers running on headers or "ribbons" that have been in use for some time for spreading asphaltic concrete.

It is questionable if the best results can be obtained if mixes containing solvent, especially the MC series of cutbacks, are rolled without aeration. This leads to the logical question: Why use cutback asphalts at all? There is no essential difference between the so-called low cost dense graded plant mixed bituminous surfacing and the standard asphaltic concrete, except that the latter requires greater accuracy in proportioning methods, separate weighing of dust, finishing to side forms, contains hard asphalt, and is placed very hot. There is little question but that granted a firm and suitable base, without which no bituminous surfacing should be placed, the heavier the asphalt the more durable is the wearing surface, provided we do not employ an asphalt which is so hard that it becomes over-brittle and cracks during cold weather.

With this fact in mind, on a Bureau project in Crater Lake National Park where a bituminous paver was being used, we substituted for the RC-3 grade specified a few barrels of what we term 95+ liquid asphalt, which is really an "E" grade asphalt of about 180 penetration, being careful to have the mixture delivered at about 150 degrees F. The operator of the spreading equipment reported that there was no difference in the facility of manipulation of the two mixtures, which indicates that a comparatively heavy asphalt can be used under these conditions. Roughness readings show the entire project to be smoother than any we have constructed by blade-spreading methods.

Following out this same idea, Oregon recently completed with their own forces an experimental section under similar conditions, using an asphalt of 50 to 60 penetration with their standard asphaltic concrete aggregate, grading and spreading with the paver. Three sections were laid, one of 2½-inch compacted thickness on a comparatively rough bituminous base without leveling, a second of 1⅝-inch compacted thickness on a previously leveled bituminous base, and a third of two courses consisting of a 1½-

inch compacted base course with a 1-inch compacted top course on a rough bituminous base. The mixture was delivered to the spreader at a temperature of 250 degrees F. On all three sections no difficulty was encountered in spreading, and completed sections present an excellent appearance both as to rigidity and uniformity of texture. The section laid in one course on a non-leveled base is noticeably less smooth riding than the others, which indicates that spreading in two courses is desirable unless the base is smooth and uniform.

The success of these experiments has convinced us that with the mechanical paver type of spreaders the benefits of the heavy asphalt mixtures can be obtained at little if any greater cost than that of dense graded (Class "F") plant mixed surfacing with cutback asphalt. It is interesting to reflect that we are on the threshold of completing the cycle from the choice between asphaltic concrete or dusty roads, through years of the popular use of low viscosity and consequently easily manipulated but short lived "road oils," and back to the general use of asphaltic concrete. Progress on this cycle has been due largely to improvements in the efficiency of mixing and spreading equipment.

Seal Treatments

Seal coats are indispensable in the Northwest area. The purpose of the seal treatment is, of course, three-fold: first, to form an enriched surface to resist traffic wear; second, to prevent the destruction caused by the permeation of moisture into the mat; and third, to create a non-skid surface. It has been our experience that the most durable of the dense graded mixed surfacings are those which have a comparatively low percentage of bituminous material and are sealed with a surface application of rapid curing liquid asphalt covered with stone chips. Unless the proportioning of the mixture is on the lean side, the action of traffic on the mat gradually closes the voids in the mixture and displaces the bituminous material, resulting in unstability of the mat and "flushing" in hot weather. On the other hand, a mixture with a minimum percentage of bituminous material, if left unsealed, would probably ravel under traffic.

The need for waterproofing a mixed bituminous surface has been recognized generally for some time. This is particularly important to us in the mountain and coast regions, as the rainfall is heavy and alternate freezing and thawing of snow water takes place during the spring season.

To develop non-skid surface qualities it was quite convincingly demonstrated by the experiments reported in Iowa State College Engineering Experiment Station Bulletin No. 119 that the "sandpaper" texture is the most resistent to skidding. This and the experience of "rumbling" of tires over large seal stones have caused a general reduction in the sizes of cover aggregate being used. It is noticeable, however, that in vicinities where a thin coating of ice forms on the road surface following a period of thawing or heavy rain, the coarser stones will project above this coating and render a surface non-skid that would otherwise be slippery. Even so, it is doubtful if this occasional superiority justifies use of the larger stone.

Our usual procedure in applying the seal treatment is to spread 0.3 gallon per square yard of RC-3 liquid asphalt and cover this immediately with 0.006 cubic yards per square yard, or approximately 15 pounds, of hard rock chips passing a ⅜-inch sieve and retained on a No. 3 or No. 4 sieve. In the mountainous regions we have encountered difficulty in securing a thorough bond between the stone chips and the bituminous material when the chips are wet and cold and the atmospheric temperature is unfavorable. For this reason District One of the Bureau expects to make use of a double-application emulsified asphalt seal coat, a heavy application to be made before the spread of stone chips and a light one after, followed by sanding to permit the flow of traffic after the emulsion has "broken." We have used this type of seal in penetration macadam work with good success in spite of adverse weather conditions, and find the cost to be but little more than the cutback asphalt seals. This type is also less likely to soften and "bleed" in hot weather.

Many of the road mixed bituminous surfacing projects in Montana have been sealed without a cover of stone chips, since chips were not available economically. For this purpose a light application of the RC-1 liquid asphalt, approximately 0.12 gallon per square yard, was used and allowed to penetrate into the surface of the mat. This does not decrease the natural non-skid characteristics of the mixture, yet it toughens and waterproofs the surface. Montana is now using a modified RC-1 which is a combination of a lower-penetration base asphalt and a more volatile solvent, but which has about the same viscosity as the standard RC-1. This modified product hardens sufficiently to carry traffic in from 20 to 30 minutes.

Conclusion

The foregoing discussion deals primarily with practice in the Northwest; yet our experiences are but a local phase of what is recognized among progressive engineers as the current trend toward closer coordination of highway design and construction with the results of experimental and research activities and toward increased emphasis upon laboratory control. Future experience will doubtless dictate further modification, but in the main the established underlying principles, which we feel are sound, will continue to govern.

DEVELOPMENTS OF PRACTICAL DESIGN AND CONSTRUCTION OF BITUMINOUS SURFACES, SPECIFICATIONS AND CONSTRUCTION PROCEDURE FOR BITUMINOUS TOP SURFACES ON OPEN GRADED TYPES.

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This paper deals with present practice in states comprising Group No. 1 and is based on specifications and procedure of the highway departments of Washiington, Oregon and California.

Bituminous types to be considered include Road Mix, Plant Mix, Penetration Bituminous Macadam, Open Type Asphaltic Concrete and Light Mats.

In Washington and Oregon the trend has been away from, rather than toward, road mixes. However, jobs have been awarded recently and are now under construction, in both states, for this type. In Washington, due to the heavier rainfall on the coast, a substitution of MC-2 material has been made for the SC-2 road oil. This material sets up faster and usual procedure requires all bituminous treated aggregates to be spread during the day of application, because of possible cold fogs and rainfall. Beneficial results are expected from the use of MC-2 by having quicker set in case of cold fogs or rainfall and a hardness to the mat that should mean lower future maintenance costs. Oregon has tried a road mix specification where RC-3 cutback material is being used. This job is located in the south central section of the state, where the climate is hot and dry. Very favorable results are being obtained. This material, being rapid in its action, must be worked and spread the same day the asphalt application is made. Aggregates are obtained from nearby pits. The material is passed over a "grizzly" with 1½-inch openings. There is no crushing or further grading of aggregates. From 50 to 60 per cent will pass a No. 10 sieve and from 4 to 12 per cent of that size will pass a No. 200 sieve. The RC-3 material is being distributed during the early morning hours of the night, mixing from about 5 a. m. to 3 p. m., followed by final spreading and rolling by 6 p. m. Construction methods in the three Pacific coast states are very similar; all require rolling rather than traffic compaction. Differences in specifications for asphaltic materials are generally due to type of aggregates and climatic conditions. Prices, by contract, run from $2,200 to $2,700 per mile of 18-foot roadway, for a thickness of 2-inch, with aggregates costing on an average of $1.50 to $2.00 per cubic yard and bituminous material at $20 to $25 per ton, the variance in costs being due to cost of aggregates, freight rates and type of bituminous material used.

Plant mix is in use more generally in Washington and California than in Oregon. Local aggregates have some bearing on this. The U. S. Bureau of Reclamation decided on this type for the road leading to Coulee Dam, and the streets of "Engineers Town" at the site, and obtained very satisfactory results. Washington formerly used a two-bin segregation of aggregates and a road oil or 95 plus material, but have now changed to a four-bin segregation and are using either an RC-3 or RC-4 cutback asphalt as a binder.

Aggregates for this four-bin segregation must comply with the following gradings:

Pass	Retained	Per Cent
1½-in. screen		100
1½-in. "	¾-in. screen	15-25
¾-in. "	¼-in. "	20-40
¼-in. "	No. 10 sieve	12-24
No. 10 sieve		25-40
	Passing No. 10 sieve	
No. 10 sieve	No. 40 sieve	25-55
No. 40 sieve	No. 80 "	15-40
No. 80 "	No. 200 "	12-30
No. 200 "		8-16

In reference to the size of the openings in the screen on the paving plant, specifications state there shall be a minimum opening of 1/10 inch and a maximum opening of not to exceed 1½ inches, other openings to be as the engineer may direct.

It is anticipated there may be some slight increase in the cost per ton for such mixtures, but results obtained will justify this. Use of this mixture has been principally on the east side of the Cascade Mountains, where the climate is dry and hot during the construction season. A 27-mile long road of this type, using RC-3, was constructed to Coulee Dam. The roadway was 22 feet wide, 2½ inches thick, except for each outside foot where it was 4 inches thick. This road carried nearly all of the heavy hauling to the dam, prior to the completion of the railroad, in an excellent manner. The costs for the plant mix and seal coat, that was later applied, were $7,500 per mile for the 22-foot width. Oregon, for a four-bin segregation, requires the following sizings:

Pass	Retained	Per Cent
1¼-in. screen		100
1¼-in. "	¾-in. screen	20-30
¾-in. "	¼-in. "	22-36
¼-in. "	No. 10 sieve	12-20
No. 10 sieve	No. 200 "	16-26
No. 200 "		2-5
	Passing No. 10 sieve	
No. 10 sieve	No. 40 "	30-50
No. 40 "	No. 80 "	16-32
No. 80 "	No. 200 "	16-32
No. 200 "		8-16

California has two types of plant mix, one called "Slow Curing," the other "Medium Curing." SC-2, MC-2 and MC-3 are used in the prime coats, mixtures and seal coats. Their requirements for a two-bin segregation are:

Pass	Per Cent
1-inch	100
No. 3 sieve	52-66
No. 10 "	36-48
No. 40 "	20-30
No. 200 "	6-11

with the additional provision that, "The material shall be so graded within the above limits that of the total aggregate not more than 20% nor less than 10% will pass the 3-mesh sieve and be retained on the 10-mesh sieve; not more than 22% nor less than 10% will pass the 10-mesh sieve and be retained on the 40-mesh sieve; and not more than 20% nor less than 10% will pass the 40-mesh sieve and be retained on the 200-mesh sieve." They have asphaltic material specifications that are not in use in the other two states. This material is called ROMC and means, Road Oil Medium Curing. The specification calls for a 90-95 road oil, blended with a kerosene solvent. There are five grades of this material being produced, with a kerosene content ranging from 27% in ROMC-1 down to a kerosene content of 11% in ROMC-5.

In the bituminous macadam field, all three states are advocates of this type. Oregon has probably taken the lead, starting in 1923, in the development of specifications, with Mr. R. H. Baldock, State Highway Engineer, taking a very enthusiastic interest and sponsoring the "Multiple Lift" type of construction. "The multiple lift construction may be described briefly as a process of constructing bituminous macadam by placing the rock and asphalt in alternate layers and spreading the stone by machines. This method insures a more uniform coating of the stone by the asphaltic cement and results in a very smooth riding surface. The freedom from roughness is due to the even distribution of stone from the spreader boxes attached to the hauling trucks and to the repeated smoothing of each layer of lift of stone with motor graders of long wheel base. The size of the stone, the number of layers, and the amount of asphalt used depends upon the thickness of the wearing surface desired, and varies in compacted thickness from 1½ to 3 inches, according to the volume of traffic," as quoted from a description of this type by Mr. Baldock. Specifications for the true macadam do not vary a great deal in the three states as to the size of the aggregates, the maximum size being usually slightly less than the completed thickness of the pavement, which is usually laid to a thickness of from 2 to 3 inches. Various asphaltic materials are used. This difference in types is usually due to climatic conditions and nature of aggregates used, and we find the specifications in the three states calling for any of the following asphaltic materials: RC-4 cutback, 95 plus road oil and "E" grade asphalt, with a soap and water solution. This soap and water solution is carried on a separate tank, mounted on the asphalt distributor. Usually the tank contains about 150 gallons of this solution. A separate spray bar for applying this solution, set about 10 inches ahead of the asphalt spray bar was in use until two years ago, when it was found the solution could be combined with the asphalt in the spray bar and applied with it through the same nozzles. The purpose of the solution is to give more rapid flowing and greater penetration to the "E" grade asphalt, 130-150 Pen. Results seem to indicate the use of any of these asphaltic materials will bring favorable results in construction. Oregon has more opportunities to use crushed rock than is the case in Washington where crushed gravel is generally used. It is interesting to note comparisons of costs between Washington and Oregon, where freight rates on asphaltic materials are nearly on a par, on some 1936 bituminous macadam construction. In each case crushed rock was used. In Washington at a cost of $2.67 per cubic yard; in Oregon at a cost of $1.94 per cubic yard. Washington used a 95 plus road oil throughout; Oregon an "E" grade asphalt, with soap and water solution, in the top course and either emulsified or cutback asphalt in the seal coat. The job in Washington is on the coast side of the mountains, while in Oregon it is on the east slope of the Blue Mountains in eastern Oregon. Costs per square yard of bituminous macadam, including the seal coat, were for 2¾-inch thickness in Oregon, 47 cents, and for a 2½-inch thickness in Washington, 54 cents. Ballast or foundation material was handled in previous contracts and in one case consisted of 8 to 11 inches of crushed rock on a 7-inch old oiled macadam road. In the other case was a 9-inch rock ballast and gravel borrow, placed on a new grade, with a 5-inch crushed rock base course for the bituminous macadam. All three states are giving more serious consideration to foundations and drainage than heretofore, and realize that no road building material, no matter how perfect the specifications, can be better than its base. Jobs as above described used bituminous material costing from 11 to 13 cents per gallon, in place, and including ballast and base course for Washington, and base course only for Oregon, gave an average cost for all construction of $1.00 per square yard. This season both Jaeger and Adnun bituminous spreading and finishing machines have been used on bituminous macadam projects. Although these machines were not primarily designed for rock spreading, they have given very good results for such operations and have met with the approval of engineers and contractors. Side forms are not used when these machines are operated and generally are not called for in the specifications for Northwest construction, but are included in the California specifications, with the provision that they are to be removed after the completion of the work. Due to the accessibility to the refineries, California uses more different grades of asphaltic materials than either Washington or Oregon in their low cost surfaces and intermediate types of pavements.

There is no intent to go into any detail in regard to asphaltic concrete construction or specifications in this paper, though its use is fairly extensive on the Pacific coast, but some recent developments in re-surface are worthy of mention. Reference is made to a specification developed by the Oregon Highway Department. This is a so-called "Cold Mix." The asphaltic material is RC-4 cutback. Specifications call for the mixture to be heated to 135 to 175 degrees F. at the paving plant and to be not less than 125 degrees F. when laid. Aggregates are heated to a maximum of 200 degrees F. and the RC-4 material to 175 degrees maximum. Mixing procedure is in accordance with usual practice in mixtures of asphaltic concrete, screening the aggregates, dropping into a weigh box, then into a twin type pug-mill mixer and adding the RC-4 material to the properly proportioned aggregates in the mixer. A mixture of this type, due to the use of the RC-4 cutback asphalt with a naphtha content of from 15 to 18 per cent will, after rolling, show a slight movement for from three to five days after placing if a roller is again used on the wearing surface. This delayed set makes it possible to correct irregularities and secure smooth riding qualities. The specifications further provide that "the rolling of the cutback asphalt wearing surface will not be considered completed until the specific gravity of the compacted material is not less than 80 per cent of the specific gravity of the combined aggregate." This produces an "open type" wearing surface that is comparable to other mixtures of this nature, yet using some other ingredients in their specifications, as gasoline, kerosene and hydrated lime. Two specifications have been adopted, one for a ¾-inch thickness and one for a 1½-inch thickness. These mixes are designed to be placed on tight bases or old, repaired pavements, and while the wearing surface is very open it is highly successful in non-skid values. The sizing of aggregates was made to as nearly as possible conform to the gradings of a crusher run product with the thought of economy through the use of such material. As these specifications are not as yet in the printed Oregon State Highway Department Standard Specifications, the liberty is being taken of including them in this paper:

For ¾-in. Thickness

Pass	Retained	Per Cent
¾-in. screen	¼-in. screen	40-50
¼-in. “	No. 10 sieve	27-37
No. 10 sieve	No. 200 “	12-16
No. 200 “		2-4
RC-4 cutback asphalt		5-7

For 1½-in. Thickness

1¼-in. screen	¾-in. screen	22-32
¾-in. “	¼-in. “	40-48
¼-in. “	No. 10 sieve	13-23
No. 10 sieve	No. 200 “	3-5.5
No. 200 “		0-3
RC-4 cutback asphalt		4.5-6

For All Sand

No. 10 sieve	No. 40 sieve	46-66
No. 40 “	No. 80 “	12-20
No. 80 “	No. 200 “	6-18
No. 200 “		12-20

Prior to contracting this type of construction, experimental or demonstrating sections were laid on main highways and, after proving to be a success, contracts were awarded for re-surface projects and later as a wearing surface for full length pavements in and near Portland, Oregon, and in Vancouver, Washington, where there is very heavy traffic. Usual bid prices for this mixture are from $6.00 to $6.50 per ton, in place.

The three coast states use bituminous mats of a penetration type for roads having light traffic or for temporary construction prior to the use, in from one to three years, of a heavier form of construction. These mats are referred to as Armor Coat, Oil Mat Surface Treatments and Light Bituminous Treatment, and are generally laid to a thickness of not to exceed one inch. Wearing qualities are good and if there is a well drained, properly stabilized foundation, the life of the mat will be greatly extended and be good for a long period where only light traffic is borne. Coats would, no doubt, vary from 20 to 30 cents per square yard, in place, on the roadway. A typical Armor Coat specification for California would require the use of coarse screenings passing a ¾-inch screen and retained on a ½-inch screen, with which fine screenings are used, passing a ½-inch screen and retained on a No. 10 mesh sieve. In the construction the base is thoroughly cleaned and a SC-1A road oil is used as a prime coat at a rate of from one-fourth to one-third gallon per square yard. Not less than five days after this prime coat is applied, the 90-95 road oil is spread at a rate of one-eighth gallon per square yard and covered with a layer of the coarse screenings at a rate of 60 pounds per square yard. A blade or drag is then used for smoothing and the course is rolled. A second application of the 90-95 road oil is applied at a rate of three-eighths gallon per square yard and is covered with fine screenings at a rate of from 20 to 25 pounds per square yard. The surface is then broomed and rolled, the brooming with non-revolving brooms and preferably attached to the roller. In addition to the SC-1A and 90-95 road oil, we find on the coast that other SC material, MC types, RC types, "E" grade asphalt and emulsions, are also being used in the various mats of penetration construction, with what appears to be equal success.

Year by year the people of the Pacific coast are becoming more and more bituminous-minded and are taking pride in their mileage of bituminous constructed roads. California continues to carry on extensive bituminous projects, with the other two states preparing old roads for bituminous types and in the meantime laying many miles each year. The three state highway departments are to be commended for their progress along the lines of present bituminous practice.

DEVELOPMENTS IN BITUMINOUS SUBGRADE TREATMENTS IN MISSOURI AND NOTES ON SURFACE TREATMENT TENDENCIES IN IOWA AND MISSOURI.

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Missouri State Highway Department**

At the first annual Bituminous Conference of this group of states, held last year, the writer presented a paper describing experiments being performed in Missouri directed toward the stabilization of subgrade soils, and soil and aggregate mixtures, for the purpose of providing suitable bases for low or medium cost bituminous surfaces. It is the purpose of this paper to visualize in so far as possible the progress shown to date without, however, attempting to formally report or to produce data or conclusions which would be premature.

The plan of attack of the work previously described involved the determination by field trial whether or not subgrade soils, and various combinations of soils and aggregates, retaining soil as the major phase, could be waterproofed by bituminous treatments with a sufficiently small quantity of treating agent to still retain the inherent stability of the soil, or, in other words, without inducing plasticity because of excess binder. The further purpose was to determine the amount of granular material required to retain or recover stability in case the quantity of bituminous material required for waterproofing should prove to be sufficient to produce plasticity and consequent loss of stability.

In addition to the field experiments described, mention was also made of fundamental laboratory studies being made in cooperation with the Bureau of Public Roads and the University of Missouri, having as a goal the chemical stabilization of soils by the use of any type of chemical treatment including bituminous oils, etc., as chemical treating agents.

It is regretted that this paper is due at this time as it is becoming apparent from current developments that much more information may be available in from two to three months than is obtainable at the present time.

Field Experiments

As described in our previous paper, the field experiments started last year included approximately forty sections, involving variables of treating agents and various quantities of added granular material and constructed by the suboiling method. About the same number of sections with similar variables were constructed by the Barber-Greene traveling plant mixing method.

The advantages predicted for the suboiling method were greater economy through the elimination of one or more operations and less interruption of traffic. The advantages hoped for from the mixing method were greater uniformity and better control.

The following is a brief discussion of the results obtained with each method to date, bearing in mind, however, that a sufficient time has not yet elapsed to permit the drawing of many definite conclusions.

Suboiling Method

The sections built by this method were constructed late in the fall and early in the winter, the process of diffusion being apparently arrested in a number of cases by cold, freezing weather. Observations seemed to show that the diffusion took place as a result of the upward movement of the reservoir of oil placed at the bottom of the scarified layer rather than by a wick action as had previously been assumed.

In general, based on degree of diffusion obtained, the emulsion sections would at present receive the highest rating, the SC sections next highest and the MC sections the lowest.

The emulsion sections required no reworking, came through the winter well diffused and were covered with a surface without additional expense.

The SC sections, in general, showed fair to good diffusion considering the weather conditions. Reworking was necessary, however, in some cases.

The MC sections apparently fractionated to some extent in the soil and produced nonuniform diffusion, requiring considerable reworking. Results obtained previous to the construction of these particular sections and during more favorable weather conditions would indicate a good possibility of the MC type showing greatly improved diffusion under better temperature and weather conditions.

In the above connection it was learned that sections showing selective or incomplete diffusion could be greatly benefited by rescarifying, blading to a windrow and back over the surface. A single blade was able to handle the entire mass in two windrows, and the material when respread and compacted seemed to knit into place without the addition of extra binder. The estimated cost of such reworking was from two to three hundred dollars per mile. If such a reworking should ultimately prove entirely satisfactory, it should prove a highly desirable corrective measure in connection with this type of work.

The presence of moisture, as anticipated, proved highly beneficial and is reflected in the better diffusion obtained in the case of the emulsion sections. The minimum moisture contents for our soil types will probably be as follows: sandy 7%, silt 10%, clay 15%.

The range of quantity of bituminous material desirable for use would at this time seem to be about 5 to 8 per cent. Our results thus far rather definitely establish the detrimental effects of an excess of treating agent, worse failures being noted at the richer end of the range used than at the leaner. As anticipated, an excess of oil produces a plastic condition which induces early failure unless compensated by additional aggregate. Information in regard to the leaner end of the range is not so complete or definite at this time. It is believed that sections now under observation will yield additional information by the end of the year.

Advantages from the use of additions of soap are not apparent at this time, the effects either being clouded by other variables or are to become apparent at later ages.

The entire suboiling project has been covered with an armor coat consisting of three to four-tenths gallons of RC type cutback and 35 to 40 pounds of half-inch limestone chips. A prime of approximately three-tenths gallon of MC-2 was used before the armor coat application. Later experiments will probably include variations in prime and armor coat.

Mixed Method

The anticipated advantages of the mixing method seemed to develop to the extent that, in general at least, a uniform mixture was obtained.

Quantitative effects of water percentages were not apparent under this method due to the fact that an excess of water was necessary to enable the pug-mill to handle the mix (approximately 35 gallons per cubic yard). The mixtures cured out without any disadvantages noticeable, due to excess moisture.

The same general range of quantity of treating material would at present be recommended for this type. Failures due to excess oil are just as apparent as is the case with the suboiling method. In addition, some lean sections, not yet covered with prime, are developing shrinkage cracks. This development encourages us to believe that we may obtain some better information as to the desirable end point in leanness than was the case on the suboiling project.

No reworking was necessary on this project except in an attempt to cure out and stabilize a few sections which became plastic due to excess of oil. We have hopes that the aeration of the mass plus some granular material may render such sections serviceable.

A rating such as was given under suboiling is not possible at present with this method, as the mixing was apparently uniform, and variations in behavior of the sections, due to the type of material used, will probably only be noted when differences in durability of the resulting mixtures become effective some time in the future.

As was the case on the suboiling project, no effects from soap additions are apparent at this time.

Sections on this project intended to check the possibilities of mixing bituminous materials with soil with no granular material content were lost due to granular material being remixed with the section by a maintenance operation when winter weather caught the operation with the mass uncured. Accordingly, this phase of the experiment will require repetition later.

All sections on this project were primed half width during the present season and have carried traffic successfully both on the primed and unprimed width. The priming will be completed and an armor coat similar to that described for the suboiling section will be laid on this project during the next few weeks.

A general comparison of the two types of work is difficult at this time, although some comparative ideas can be obtained from the previous discussion. The general soil types differ radically, the suboiling being mainly on silt while the mixed method is on a clay subgrade.

There are at this time more good sections on the mixed method project than on the suboiling project, but the best sections of each method, where comparable, could probably be said to be equally satisfactory at this stage of development.

As previously suggested, we hope to obtain a great deal more information from detailed observation and study of these projects. Our results to date are sufficiently encouraging to us that we have let or are in the process of letting approximately sixty miles of development projects for construction this season.

These development projects will include certain variables selected from observations made on the experiments described, and should serve to develop certain types of information more rapidly than would be possible by a repetition of the shorter sections previously utilized.

Laboratory Research

Our cooperative laboratory research concerning the influence of the chemical composition and kind and amount of adsorbed bases on the affinity of soil constituents for bituminous materials is being continued. General conclusions thus far reached, and which were discussed by Dr. Winterkorn at the International Soil Congress, are:

1. The Affinity of a soil for bitumen increases with decreasing silica sesqui-oxide ($SiO_2 - R_2O_3$) ratio.
2. Kation exchange can be used to improve the affinity for bitumen; iron, alumina and potassium ions have a beneficial influence; sodium has a distinctly detrimental influence.
3. Cracked bituminous materials appear to possess a greater affinity for soils than do noncracked materials.

A forthcoming paper on this subject will be available in the near future when released by cooperating agencies.

NOTES ON SURFACE TREATMENT TENDENCIES IN IOWA AND MISSOURI

Iowa

The work this year consists almost entirely of the inverted penetration type. They have only one project of road mix mat, ten miles in length. On this project tar is being used.

On the blotter type construction, the heavier grades of SC and MC type oils are being required, much of the oil furnished this year being SC-7 and 8. They have not used any of the RC grades. They prefer crushed stone as an aggregate but permit either crushed stone or gravel.

Surfaces mentioned are placed on road stabilized six months in advance by addition of approximately 1500 cubic yards of aggregate per mile plus binder from the old road surface.

They feel that surfaces thus obtained are consistently satisfactory except that no definite provision has been made for increasing the thickness of base in accordance with the lack of stability of subgrade with change in character of soil.

Sections of road, known by the Maintenance Department to require same, are given frost boil treatment in advance of stabilization of base. This is usually a uniform layer of approximately one foot of gravel with about six to eight inches of soil cover.

Missouri

Coarse graded types such as retread are being abandoned in favor of dense graded types such as oil mat.

A considerable mileage of armor coat is being laid as a temporary treatment in order to allow for the development of weak spots in unproven bases prior to later construction of higher cost surfacing.

The trend in high type surfacing is toward the use of more coarse aggregate (one-half inch), developing a surface rougher in texture than formerly employed. The high efficiency of plants manufacturing these mixtures and the wide variety of aggregates made available have resulted in making these mixtures more highly competitive with so-called lower cost construction than has heretofore been the case.

More attention is being paid to the thickness of the base course underlying the mat. When originally started in this state, bituminous mats one inch thick were placed on any base that happened to be available on the job. Last year's practice required a stabilized base at least three inches thick on which a two-inch mat was placed. We believe that eventually it will be found economical to have a total thickness of mat and base of six to seven inches on bad subgrades and three and one-half to five inches on fairly good subgrades.

During the past four years there has been a definite trend for the use of tar as a primer in this state to the point that at present it is used almost exclusively for this purpose. The principal advantages claimed for tar over an SC or MC primer are: first, more rapid penetration, hence a more rapid curing which permits the contractor to carry on the next operations sooner; and second, a more uniform distribution of the bitumen throughout the depth of penetration. When the SC and MC bituminous materials are used for penetration purposes, there is sometimes a selective adsorption of some of the materials which causes the formation of a hard crust on the surface. This crust breaks up very easily under the subsequent construction operations.

There has been a definite trend away from the type SC oils toward the use of type MC. The latter seem to be much more weather-proof than the former, particularly when used with an unfilled aggregate, which, when mixed and compacted, would be somewhat permeable to water.

There is a definite trend toward the use of aggregates as they naturally occur in the deposits, rather than requiring a filled aggregate, the gradation of which is confined to a very narrow range. In most localities of this state this means that we are using an unfilled aggregate, although at the same time one which would be called "dense graded." This has been made possible through the use of the more weather resistant type MC oils.

Aggregates are now measured by weight instead of by volume as was done when construction of this type was first used. While of no particular advantage to the state, this is an advantage to the contractor in that he does not have to gamble on the bulking of the aggregate which ordinarily he purchases by weight and under the old system sold to the state by volume.

On projects where a seal coat was not called for in the specifications, the practice of holding back the equivalent of .15 of a gallon per square yard from the oil which would ordinarily be included in the mixture and later applying this oil as a penetration coat to the surface of the compacted roadway, has been developed. This enriching of the upper layer of the mat makes for a more waterproof and weather resistant surface.

There is a definite trend at present toward using a high grade asphalt seal coat on all bituminous mat construction, applied some time before the mat enters the first winter. Experience over the past three years has shown that the cost of the seal coat is amply repaid by the increase in the life of the mat.

DEVELOPMENTS IN PRACTICAL DESIGN AND CONSTRUCTION OF BITUMINOUS SURFACES IN WYOMING.

By W. A. Norris, Highway Contractor,
Cheyenne, Wyoming

In 1923 the Wyoming Highway Department found itself considering the proposition of a ten-year highway program which would result in a definite road system constructed on certain standards, which at that time meant natural soil subgrade, crushed gravel or rock base courses and clay bound crushed rock or rock base courses and clay bound crushed rock or gravel surface courses. Such a program was hailed as political propaganda, and next to impossible of accomplishment, since in a state so sparsely settled, with long distances and major streams to bridge, the financing of many miles of road of any type higher than the then-familiar rut trails seemed to present insuperable obstacles.

By 1925, however, considerable mileage had been graded and gravelled and the planned program was definitely on the way. The routes, standards of construction and apparent progress were developing much as planned, and the inevitable chronic complainers turned to criticisms of dust and corrugations from the travelling public and the high cost of none-too-successful maintenance by the Highway Department.

About this time, California was in the limelight for its accomplishments with an oil-treated road surface. Wyoming having several oil refineries within the state, began the experimental construction of three or four short sections of oil-treated gravel roads. Not much was known of specifications for the oil to be used, and no particular attention was given to the grading and quality of the surfacing aggregates. As a matter of fact, the so-called road oils first used were "still bottoms" diluted with fuel oils, distillate and what not. No attention was given the nature of the crude, and as a consequence I believe we were using quite indiscriminately residues from paraffin, intermediate and asphalt base oils, without much knowledge of their properties. As a result, we had little success—in fact, the surface produced frequently resembled what might be found in front of any country garage where crank case drainings have been thrown to settle the dust. After one or two good rains there was no oiled surface. Results were more than discouraging over a period of two or three years, while traffic conditions increased the demand for a better surface, and the meagre state income demanded lower maintenance costs.

In May, 1928, Wyoming sent one of its department engineers to California to study the methods and materials used in such construction as the once-famous Victorville section of road mixed oil mat. After spending two weeks in California visiting several jobs in all stages of construction, and having delved into the mysteries of road oils, their source, character and specifications as well as the source, character and grading specifications for aggregates and getting a mind's eye picture of what stain test should look like, Wyoming's ambassador returned to find that the refineries of Wyoming were not equipped to turn out oil that would do the job.

California road oils were imported and the first two hundred miles of oiled road in Wyoming were built. Soon the Wyoming refineries revamped their plants and by selection secured crudes that produced satisfactory road oils until today the production, refining and sale of Wyoming road oils has become of major importance.

In 1928 some 85 miles were constructed—specifications used seemed at that time to be very close but compared to the control of today they were elementary. When we consider the early specifications and their enforcement, with presentday procedure, beginning with the subgrade and up through the grading of aggregates and characteristics of the oil, we look back and wonder how we developed as good roads as we did; and assume that our diligent efforts and enthusiasm with a new idea must be the reason.

Wyoming never has made a special concern of its sub-base except to build higher than average grades and make every effort to provide for good drainage. As a consequence, and as Wyoming is a relatively dry state, we have few failures due to sub-grade conditions. Our base courses are for the most part reasonably well graded crushed rock, gravel or hard laminated shales. The base course section is never less than four inches thick and under certain poor grade conditions, as much as six inches.

Base courses are tight, but the quantity of binder is held to a minimum that will assure both density and stability. For both base and top course aggregates Wyoming requires material passing a one-inch round screen, which practice precludes the possibility of bringing up larger particles from the base into a finer graded top course when the surface is reworked.

Until about 1932, the width of roadway did not exceed twenty-four feet, with a twenty-foot oiled width usually having three inches of base course gravel and three inches of oil-mixed wearing surface. In later years, the tendency was toward a wider roadway. In 1932, 1933 and 1934, width had increased to twenty-eight feet, with a twenty-two foot oiled section two and one-half inches thick, while the present roads are being built thirty-four to thirty-six feet wide with a twenty-four foot oiled section one and one-half inches thick on a penetrated base. The cost per mile of the completed road has changed very little; improved and more efficient machinery and production methods have reduced unit prices until grading, gravelling and oiling today, in spite of higher standards of construction, is practically the same as ten years ago.

In 1928 the oils used were entirely what we now know as the SC type. In later years the MC type, and in several cases, the RC type has been used in both road and plant mix. Wyoming has very little plant mix and none has been constructed during the last four years. We do use several of the travelling road mix outfits such as the Barber-Greene, but the most popular is the Wood mixer which for the last three years has been on ninety percent of Wyoming contracts.

All oil mat construction calls for an RC seal, RC-1 without cover usually being specified. Frequently on heavily travelled routes an RC-2 stone chip treatment is given after two to three years of service. This procedure has the effect of stage or progressive construction. Since practically all of our surface chips are of limestone or light colored quartz gravel, the road surface has been made lighter in color much to the approval of the night drivers.

During the last two years, Wyoming has been constructing many miles of road known as base stabilization. The surfacing of four and one-half inches of crushed rock or gravel is placed in the new grade immediately upon completion of the grading and some six months later, or at least by the following summer, the top inch and one-half is bladed up and placed in a windrow.

The base is wet and rolled, if necessary, and binder added if loose to insure compaction, following which is distributed about three to four-tenths gallon per square yard of MC-1. When the base is dry, the windrow is treated with MC-3, mixed, laid and rolled in the customary way. Such treatments have proven entirely satisfactory for several years and have given our road system a dustless, smooth-riding character that has brought much favorable comment. Of course, later construction will be undertaken to place additional oil-treated gravel on these surfaces, but their ability to serve an urgent present demand as well as reduce maintenance costs has been our salvation.

From my personal observation, I believe we are securing no better oil mats than we did in the beginning, but as a result of study, experiment, and improved equipment, we are securing much more road than formerly for the same amount of money. Specifications are more exacting, but we have improved equipment to meet the demands. As we have improved in our knowledge of materials, we have been able to use lesser thickness to secure equal results. We have also improved the construction quality of our bituminous products and in so doing, are securing equal or better results with less amounts. In the last few years, improved equipment has practically doubled the day's output. All in all, we are getting more miles of wider and generally higher standard road for the same money that we previously spent.

In conclusion—as a contractor, I would say that while there is no definite system of arriving at costs as they may be affected by weather on the average job, it has been my experience that the "law of averages" has permitted us to stay in business. The most severe hazard of the contracting end of bituminous construction is the same hazard as in all construction, that is to say, the personal equation of the engineer and his inspectors. I have no pick on engineers—I am one myself—having actually put in twelve years in the highway departments of two states, but very seldom do two engineers, or inspectors, analyze, interpret and enforce the same speifications in the same way. Of course, that is why we have hundreds of religious groups, sects, etc., yet all of them get their authority from the One Good Book, but it doesn't mean the same to everyone. I believe that no supervisory capacity should be allowed to unbalance his authority and responsibility—these regardless of how little or how great should be equal, and then specification interpretation will be more uniform and a contractor's life—barring his own mistakes—a bed of roses.

RECENT DEVELOPMENTS IN BITUMINOUS DESIGN AND CONSTRUCTION IN THE GREAT PLAINS AREA

By Frank S. Gilmore, Highway Engineer,
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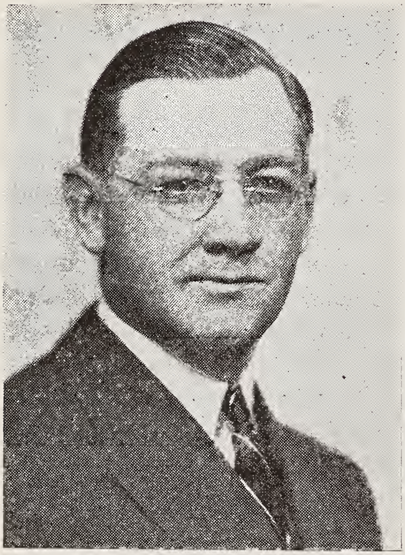

In preparing a paper on "Recent developments in Bituminous Design and Construction in the Great Plains Area," it will be necessary to touch upon some of those subjects which are to be treated in detail in other papers. Therefore, it would seem desirable to make such a paper as this as brief as possible, since the presentation of detailed discussions would undoubtedly mean a duplication of data contained largely in those papers above referred to. In this paper no attempt will be made to discuss more durable types such as asphaltic concrete, sheet asphalt, etc., of which a substantial and increasing mileage is being annually constructed.

Since, in highway design and construction, the base or subgrade is as important as the wearing surface, no discussion on the design of bituminous surfaces would, at this time, be complete without reference to base or subgrade treatments. A few years ago it was not an uncommon practice to construct, as a preliminary step, a light bituminous mat on any road upon which gravel, at one time or another, had been placed. Those light mats were of the type classified in The Asphalt Institute Manual No. 2 as surface treatment types.

Following the preliminary bituminous treatment all weak and unstable local subgrade areas, which would of necessity develop under traffic, were to be eliminated by replacing, draining, or strengthening the unstable subgrade material. After all weak areas had been sufficiently strengthened or stabilized, the original mat or surface treatment was to be further improved by replacing or resurfacing with a more durable mat of the road-mix or plant-mix variety. The theory supporting those methods of highway surface improvement were that the bituminous treatments would improve the character of the highway surface, save previous highway investments and result in the improvement of a larger mileage of highways with available funds. Subsequent improvements, often planned to be carried on as maintenance activities and paid for with maintenance funds, would eventually result in the completion of a strictly high grade highway. In the meantime, traffic would be served with an improved surface.

Such a theoretical program, if carried out, is workable, but because of a very definite improvement over the dusty, and, often times, rough or sloppy gravel road resulting from this initial bituminous surface treatment, the demand for additional miles of bituminous surfaces has frequently made it impossible to continue with the original planned mat improvement. Therefore, even though economies have been effected, results are often not so satisfactory as could have been accomplished by varying the procedure.

Accordingly, the trend now seems to be toward draining a roadway and adequately strengthening or stabilizing the subgrade and base before bituminous surface construction is attempted. In some localities base construction is receiving much more attention than was given to this subject a few years ago, and, in the Great Plains area, base construction or a type of base stabilization best suited to meet local conditions is rapidly developing.

In some sections substantial mileages of stabilized graded soil mixtures are being constructed as base courses, while in other localities crushed stone, "iron ore," caliche, gravels, chat, burned shale or other available materials are, when most economical, used extensively. In some instances earth or surface treated roadways have been ripped up to depths of as much as eighteen inches. Soil densification and consequent improved stability have then been accomplished by uniformly compacting the soil, often, at that time, incorporating such available material as would effect an improved proportion of "friction" and "binder" elements and perhaps render the soil more water resisting.

Local areas of highly unstable materials are being replaced or strengthened with an additional depth of crushed stone, a stable soil mixture or other suitable base material. The thickness of these stabilized base courses or treatments varies in different localities. The character of the subgrade soil, climatic conditions and the probable character and volume of traffic the highway will have to support are influencing factors. An average thickness of three inches with an increased thickness for local areas, where added strength is required, has been found adequate in many instances, while in other areas when roads are subjected to heavier traffic and more severe climatic conditions, base materials have been placed to a depth of six or more inches.

Throughout the Great Plains territory and adjacent prairie country, large areas exist where clay type soils predominate and where aggregate or suitable base materials is scarce and expensive. Recent studies and experiments have dealt with the treating of these clay type soils in order to develop some method of stabilizing these materials as they are found and to so utilize them as base and thus an integral part of the completed highway pavement or structure. Of course, with the use of asphalts, successful methods of economically and permanently stabilizing sands or sandy soils have been definitely worked out and reference will be made to these treatments later on.

In some localities the central ten or twelve foot lane of a gravel surfaced road, when covered with a bituminous mat or a bituminous surface treatment, has been found amply strong to support traffic, but, on these same roads, during certain seasons of the year, a marked lack of support has developed beneath the mat in the outer lanes. Improved performance has resulted by increasing the base thickness under these outer lanes only, developing in effect, a wide, thickened-edge, stabilized base treatment.

Crushed stone or soil gravel mixtures have been used in this extra base thickening or reinforcement, and results indicate that such methods are effective as well as economical. There is some favorable inclination toward designing and constructing a wide thickened edge base course of stabilized soil mixtures or other appropriate materials when such base courses are constructed as thin as three inches.

Up until quite recently numerous projects employing a comparatively thin bituminous mat (surface treatment classifications*) requiring a minimum of 400 or 500 tons of aggregate per mile have been constructed. The trend seems to be away from this thin mat type toward a heavier mat requiring from 1000 to 1800 or more tons of aggregate per mile, or, except in certain cases, toward an even lighter surface treatment. In either instance, the bituminous mat or surface treatment is placed on a base which has been stabilized, strengthened or reinforced, possibly by one or more of those methods mentioned above.

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*The Asphalt Institute Manual No. 2—Surface Treatment Types—page 7.

Except for base preparation and for bituminous materials and aggregates, these lighter surface treatments are quite similar to some "blotter" type treatments constructed a few years ago. For priming the base, present common practice requires an initial application of low viscosity bituminous material.. For this purpose an MC-1 cut-back is generally preferred, while at times an SC type material is used. Following the prime, a second application of a much higher viscosity bituminous material is applied at rates up to a usual maximum of one-half gallon per square yard. This second application is covered immediately with an aggregate, which is spread from trucks, from a windrow, or from stock piles previously deposited on the side of the traveled way. In contrast with some former methods of constructing "blotter" types, cover materials not mixed with the bituminous material by mechanical manipulation although a drag or blade is often employed for a day or two to keep any surplus cover material spread uniformly over the roadway.

Cut-backs, or high penetration asphalts, are the materials most commonly used for second applications in these surface treatments, while gravels—either crushed, pit run or screened—and chat or crushed stone, are used for cover material. One of several variations to this procedure requires that the prime be applied in two applications with a time element between each. For the heavier mat construction, dense graded aggregate continues to be popular although in some localities the trend is toward the use of a crushed aggregate containing a much larger percentage of coarse material.

In a portion of the eastern part of Kansas, for instance, mat designs and specifications requiring a coarse graded crushed limestone have largely replaced mats, constructed up until this past year, in which much finer aggregates were used. These mats, when placed on adequately reinforced or stabilized bases, are thought to be more durable, more stable and less susceptible to the detrimental effects of moisture than were the older types, especially when the older types were constructed without due regard to base conditions.

While higher stability is one of the objectives sought in using this relatively coarse graded aggregate, mats using aggregate of almost the opposite gradation have been constructed this year, and during several previous years, in Nebraska. In this Nebraska work, mats of fine sand (blow sand) with cut-back binders, have been constructed several inches in thickness on top of stabilized oil sand bases or stable soil mixtures.*[1] A maximum sized aggregate of 1½″ was employed on the Kansas coarse aggregate type of construction, and the aggregate was, according to specifications, uniformly graded between the maximum size and the No. 4 or No. 8 square mesh sieve. In contrast with this coarse aggregate the fine sands used in Nebraska "practically all passed the No. 50 sieve*[2]", and to these fine sands it was sometimes necessary to add still finer material in order to have sufficient filler content to satisfy stability requirements.

Very excellent results were obtained with both types of aggregates indicating that suitable methods can be developed permitting the efficient utilization of most aggregates in bituminous highway construction. In fact, between these two grading extremes many satisfactory aggregate combinations have been worked out and will probably continue in use. Crushed aggregates ranging in hardness from soft limestone to hard trap rock are giving good results, although an increasing interest is being shown in the character of all aggregates as indicated by accelerated soundness tests*[3], toughness tests, etc.

While the selection of an aggregate may frequently be a Hobson's choice, resulting economies and performance are apparently the deciding factors in the use of any particular material, or combination of materials, where several are available from which to choose.

Throughout states in the Great Plains area where suitable aggregates are available, an increasing interest is being manifested in a type of construction used extensively in Texas. Referred to in Texas as "Double Asphalt Surface Treatments," "Triple Asphalt Surface Treatments," etc., depending on the number of courses, these types, being of a penetration macadam

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[*1 & 2] "Sand Surfaces" Digest of Proceedings of the First Annual Montana Bituminous Conference.

[*3] Example—Present Kansas State Highway Supplemental Specifications.

variety, are constructed on gravel, caliche, or other selected stable soil bases. Like other asphalt types, these Texas "Surface Treatments" possess those easy riding qualities characteristic of modern bituminous construction. They are tough and durable, and, in the northeastern part of the state, have successfully withstood punishment from exceptional volumes of traffic, including heavy loads, to which some of them are subjected.

Employed in their construction are gravels or crushed stone, graded from maximum sizes of 1¾″ to ¾″, depending upon the course, to minimum sizes of 1″ to ¼″, likewise depending upon the course. Soft asphalt cements having minimum penetrations of close to 200 are used for binders. In procedure, asphalt applied to the previously prepared clean base is covered with the first course of aggregate which is uniformly spread and then lightly rolled. A second application of asphalt is covered with the second course of smaller aggregate which is likewise lightly rolled. Additional applications of asphalt and aggregate may follow in like order. Following the final application of aggregate, the entire surface is thoroughly rolled with "an approved self-propelled three-wheeled roller."

A new piece of road mix equipment—in fact a traveling plant—has made its initial appearance in Oklahoma on state highway bituminous mat construction during the summer of 1936. This equipment, a "Jaeger triple pugmill mixer," was developed and has been employed successfully on Ohio bituminous work of a type which has been found of interest to engineers in states west of Ohio. A description of some of the problems involved and a discussion of contemplated methods to be employed in the solution of these problems is contained in a paper by Mr. T. E. Morgan, Assistant Division Engineer, Ohio Department of Highways. This paper was presented at Cleveland on January 23, 1936, before the Association of Asphalt Paving Technologists.

The Ohio work, based on previous experiments, is a "retread" variety of construction. For coarse aggregates, slag, crushed stone or gravel, ranging in size from ¾″ to ¼″, were used. To this, finer aggregates composed of limestone screenings, sand or other materials were added in order to increase the density. Rapid curing cutback asphalts (RC-3) were used for binders.

In construction, coarse aggregate was spread over the lane of the roadway to be resurfaced. Cutback asphalt, then applied to the coarse aggregate, was immediately covered with the fine aggregate. The aggregate and bituminous materials were then mixed by mechanical manipulation. For this purpose the Jaeger triple pugmill was found to be well suited. The mixer followed closely the spreading of stone and bituminous materials. One pass of the machine was sufficient to mix the aggregate and bituminous materials, and rolling followed closely behind the mixing operations. After completing the surfacing or resurfacing of one lane, operations were repeated on adjacent lanes, traffic then using the lane or lanes on which surfacing operations had been completed.

Advantages of this type of construction are that a graveled or crushed stone road or pavement can be surfaced or resurfaced with the least possible inconvenience to traffic, eleminating the necessity of maintaining detours. By shipping the coarse and fine aggregates separately and employing them in the sequence above mentioned, segregation is eliminated.

The "Jaeger triple pugmill" mixer is not a self-propelled piece of equipment, although it contains a power plant for the operation of the pugmills and other mechanical contrivances necessary for its successful operation. Besides mixing the aggregate, the machine spreads the mixed material to a true line, grade and cross section. With a screed carried at an average height, determined by long straight edge runners, a finished easy riding surface is obtained typical of those produced with long wheel-base finishing equipment. A large crawler type tractor is used to pull the mixer down the road at the rate of from 60 to 70 feet per minute. The present capacity of this type machine is being increased so that it can efficiently handle increased quantities of the finer densely graded mixes used extensively throughout the West.

In addition to the Jaeger machine, other new equipment has recently been developed and rumors persist of still more mechanical developments. Like other equipment brought out during very recent times, new or improved machines of the future will contribute toward the further improvement of bituminous surfaces and will, of course, naturally result in additional construction economies. With the persistent demand for an expanding system of improved highways, the future construction of a great mileage of bituminous surfaces, designed to meet ever changing traffic requirements, will make it imperative that new construction and maintenance equipment be constantly developed and that existing equipment be constantly improved.

As it is true that construction requirements influence the design of equipment, it is also true that limitations of available equipment exert a positive influence on the design and construction of all highways.

Since the influence of equipment upon the design and construction of bituminous highways is so positive, no discussion of the trend of highway design and construction would be complete without mention of recent improvements in existing equipment, and of the application of the existing equipment to new uses.

Among entirely new types of equipment, developed during recent times, is the Ingalls "sub-oiler" machine. This machine, used in the Great Plains area for the first time during 1935, referred to in a number of published articles, described in the October, 1935, issue of "Roads and Streets," and further in the February, 1936, issue of "Better Roads," has now been greatly improved. As it now exists, the machine weighs about five tons, and has an increased capacity for accurately and uniformly distributing bituminous materials in the soil at a predetermined depth beneath the surface of the roadway. Power operated, and equipped with positive controls and devices which will more readily permit the machine to accurately perform the functions for which it is designed, characterize this piece of equipment as being definitely past the experimental stage.

A decided trend toward the utilization of those clay type soils, as mentioned in paragraph 8; the treatment of such soils with liquid asphalts, successfully demonstrating the stable characteristics of soils so treated; and the development of new type equipment to economically utilize liquid asphalts for this purpose, have created unusual and widespread interest in the Ingalls "sub-oiler."

In addition to the Ingalls sub-oiler, traveling mixing plants of the Barber-Green variety have been successfully used in soil-oil stabilization work. Methods employed in the mixing of soil and bituminous materials in the Barber-Green plant were described by Mr. Reagel at the First Annual Montana Conference on Modern Bitutminous Practices and also at the 1936 session of the American Road Builders' Association held at Cleveland, Ohio, during January, 1936, as well as in other published articles.

In the accurate placement and finishing of plant mix materials, mechanical spreaders of the Jaeger and Adnun types, operating without side forms, are contributing to the further economies in the production of improved bituminous surfaces possessing those desirable, superior riding qualities. Compaction of these surfaces, of course, is accomplished after spreading with these mechanical devices, by means of self-propelled or pull type rollers, often supplementing the final compaction by traffic.

Included in the list of conventional road mix type of equipment are the single blade and multiple blade graders, motor graders, distributors, rollers, etc. The trend in motor grader designs seems to be toward heavier and more powerful equipment, capable of moving a larger or heavier windrow of aggregate. All blade equipment is now available equipped with rubber tires. Improved traction is obtained on some motor graders by employing four sets of dual pneumatic tires on the driving wheels. Other motor graders are employing, for this purpose, four low pressure tandem pneumatic tires.

Improved power control for blade adjustment and other operations is coming to be standard with all blade equipment, power being applied either mechanically or through a hydraulic system. Among other improvements on these modern motor graders are larger circles, mold-boards up to 24 inches high and 14 to 16 feet in length, wider front anxles, more rigid frame construction, machines with greater capacity for adjustment with relation to the load, multiple speed transmissions and either gas or Diesel motors for power.

The trend in modern heater design is toward more compact equipment with greater heating capacity. Distributors are being designed for more efficient operation and a recent mechanical device which provides for more positive mechanical synchronization of pump speed and truck speed is coming in for much discussion. Larger pumps, tachometers, thermometers and other improved inspection, control and safety devices and arrangements are a part of the more efficient modern distributor.

Recent new designs in roller equipment have likewise resulted in much serious consideration wherever highway construction operations utilizing roller equipment are being discussed. A conventional type power roller with an auxiliary roller attachment, designed to roll out the high spots, is being employed in low cost bituminous highway construction. In stabilized soil base construction the sheepsfoot roller and a pneumatic tired roller are being used extensively and with good results, while the pneumatic tired roller is proving to be an efficient and popular piece of equipment for compacting some bituminous mixes.

In the trend of road mix versus plant mix, road mix construction continues to be popular and will undoubtedly continue to occupy an important place in highway programs. With improved equipment and improved technique developed in this class of work, uniformly excellent results are being obtained. If it were not for the fact that manufacturers are constantly improving road mix equipment, plant mix construction would undoubtedly have made greater gains. Since, with the trend toward heavier mat construction and with the development of new plant mixing, spreading and finishing equipment, there is increased interest in plant mix work, both of the traveling and stationary plant variety.

In one of the states a central mixing plant, operating at the source of aggregate supply, has furnished many carloads of bituminous aggregate mixes for an extensive widening, leveling and pavement resurfacing program.

In an adjoining state dense graded aggregates, mixed with bituminous materials at a quarry site, mixing taking place in a conventional hot plant pugmill type mixer. These mixes have been shipped in railroad cars throughout the state and have been used extensively in maintenance repair work and in surface or paving projects too small to be as economically accomplished with the usual road mix or plant mix setups.

In both road mix and plant mix types of construction the trend seems to be toward the use of higher viscosity bituminous materials. SC type materials are frequently used in combination with powdered asphalts. As the medium curing cutbacks have largely replaced SC materials, so are the rapid curing types replacing, to a certain extent, the MC liquid asphalts. Even with the fine, dense graded aggregates, the use of RC materials is receiving more serious consideration, especially in plant mix work. Here, the use of RC materials will greatly reduce the mixing time for complete aeration, frequently deemed important and necessary when slower curing type materials are employed. The possible advantages to be gained from the use of emulsions, in particular classes of work, are not being lost sight of.

Weather and other influences may affect the design and construction of bituminous surfaces. As examples: Prolonged drought, by reducing the number of construction delays, may prove favorable to road mix methods. This kind of weather may also, because of an increased seriousness of the dust hazard, cause a rapid extension of the mileage of surface treatment types. Also, because of a combination of circumstances, maintenance funds which would have been used for routine sealing and other betterment work, may be diverted for other purposes. Exceptional winters and springs may cause undue alarm and a tendency toward over-design. And labor requirements may influence the selection and use of a particular type of aggregate in preference to others.

However, the proper thing to do may be decided by serious study and a trend toward increased research, both in the field and in the laboratory, is quite evident. In the field of research, work of the U. S. Bureau of Public Roads, of highway departments and of a number of universities and colleges and technical schools is outstanding. From the results of research, new or improved applications of bituminous materials to the field of highway design and construction originate.

Those people having a responsible interest in highway developments are constantly and eagerly seeking publications and proceedings of such organizations as the U. S. Bureau of Public Roads, the Highway Research Board, the Association of Asphalt Paving Technologists and the Asphalt Institute. In addition to these publications those papers presented at such meetings as this Montana Bituminous Conference and those articles which appear in the technical press exert a powerful influence on the design of an ever increasing mileage of bituminous surfaced highways—highways which must and do keep pace with the ever changing requirements of modern traffic.

BITUMINOUS CONSTRUCTION IN OKLAHOMA

**By Carl R. Reid, Materials Engineer,
Oklahoma State Highway Commission**

Stage construction, as such in Oklahoma, has not been planned and carried out in the past to any appreciable extent. This has been due largely to changes in program of federal aid work, extensive road treatments under maintenance by state forces, and other programs as in other states which have brought about from time to time changes in surfacing work over those originally contemplated. Though there are a number of instances in the state of typical stage construction which have been quite successful, it so happens that they were originally planned in such a way that adequate records of the methods, costs and materials used are not now available so as to permit a detailed description and discussion. There has been in our work nothing unusual or different from that quite commonly used in practically all other states during the past few years.

All engineers, and particularly those charged with highway improvements, are familiar, in a general way, with the many phases of stage construction.

The details, types and methods vary with the requirements of traffic, climate, topographical and geological features of the particular area in which the improvements are to be made.

During the past few years, due to the well planned, thorough and extensive study and research of the Bureau of Public Roads, together with the several other highway research and technical organizations and individual investigators, many factors heretofore considered unimportant or beyond our ability to improve or remedy satisfactorily, have in increasing volume been furnished us for study and application to our individual problems so that we should now, with intelligent study, be able to proceed with stage construction of our highways in all cases in such a manner as to secure the ultimate in service and economy.

As you are all aware, the outstanding and, I believe, greatest fundamental development in the highway field has been given us by the Bureau of Public Roads in Soils Science. Due to this new activity we are able to understand, in a great many instances, the causes of failures in the various types of surfaces. We are then able to provide against a large part of these failures in future improvements. While this new study has provided, in a large measure, a basis for designing properly the required thickness of pavement to carry the loads, it has also given us an improved theory of design for economical stabilized base subgrade and surface course construction. As further investigations are made, more intelligent design and planning of stage construction will be effected.

Oklahoma has an unusual variation of topography, plains to granite hills and mountains, and a large variety of soils with a great deal of the heavy clays. We are quite well supplied in most sections with aggregates of different types, caliche for base and surface work in some areas, while some rather large areas provide only sand and silt as road material.

With the increasing requirement for a greater mileage or greater service in highways, Oklahoma is now taking advantage of some of the newer developments in the use and design of materials in base and surface construction.

In our studies of subgrade soils, which was started in 1933, we have, among other things, investigated existing satisfactory base courses and are now contracting and building with state forces what we believe is a very satisfactory completed base under the following specifications:

Aggregate for Gravel Base Courses

(a) Material Covered. These specifications cover aggregate for use in the construction of gravel base courses.

(b) General Requirements. The gravel base material shall consist of an intimate mixture of graded aggregate, coarse and fine, together with soil binder. Coarse aggregate (which comprises the portion retained on a No. 10 sieve) shall consist of sound, tough, durable particles or fragments of gravel, stone, disintegrated granite, or combination thereof, crushed to size if necessary. Fine aggregate (which comprises the fraction passing a No. 10 sieve) shall consist of sand, stone, dust, or other inert finely divided mineral matter, and a soil binder consisting primarily of fine soil particles which may be represented by top soil, loam or clay.

(c) Physical Properties. The gravel, above one-half inch in size, contained in this material shall have a per cent of wear of not more than twenty. Broken stone contained in this material shall have a per cent of wear of not more than ten.

(d) Gradation. The graded aggregate and soil binder shall be so combined in such proportions as to produce a final mixture conforming to the following composition limits by weight, when tested by means of laboratory sieves having square openings:

Passing	Per Cent
1½-inch sieve	100
¾-inch sieve	75-100
½-inch sieve	65-90
⅜-inch sieve	60-85
No. 4 sieve	45-75
No. 10 sieve	35-60
No. 40 sieve	25-45
Smaller than 0.05 m.m.	15-30

In no event shall that portion smaller than 0.05 m.m. exceed two-thirds of the total amount passing the No. 40 sieve.

(e) Plasticity Index—Liquid Limit. The material passing the No. 40 sieve shall have a plasticity index of not less than eight nor more than sixteen. The liquid limit of the material passing the No. 40 sieve shall not exceed thirty-five.

The higher ranges of plasticity index shall be requested when the percentage of material passing the No. 40 sieve is near the lower limit as provided in the above table, and the lower ranges shall be requested when the percentage of material passing the No. 40 sieve is near the upper limit in the above gradation requirements.

We are now questioning whether or not the percentage of material passing the 40 sieve, smaller than .05 m.m., and the plasticity index, can be further reduced safely, thus assuring that we will avoid any possibility of such completed base course developing excess capillarity or otherwise losing satisfactory stability and at the same time provide optimum density.

While we have not, to this time, constructed any stabilized base or surface courses with stabilizing agents such as calcium or sodium chloride, we contemplate on any of this type work the further reduction of the 0.05 m.m. portion and the plasticity index to below the present lower limits specified.

Other materials including caliche are in use for base and surface course work. Many of these that have been in place for some time are utilized as a part of our stage construction activity.

A new asphaltic material to Oklahoma this season is what is termed or called an "inverted emulsion," which meets the following specifications:

1. This asphalt shall be a homogeneous solution composed of asphalt, and a special solvent. There shall be no breaking or separation in storage.

2. This liquid shall not be miscible with water either before or after being applied to the road.

3. The liquid shall satisfactorily pass the following stone-coating test: Approximately 75 to 100 grams of gravel or crushed stone shall be placed in a beaker or other container and sufficient water added to completely cover the stone. Approximately 7 to 10 c.c. of the liquid asphalt shall then be added and the mixture stirred. The asphalt shall adhere to and completely coat the stone with a film of asphalt while remaining under the water.

4. Visicosity, Saybolt Furol @ 122° F. 300-400.

5. Water, per cent by volume, 0-7.0.

6. When distilled to a temperature of 680 degrees F. the oil portion of the distillate expressed as percentage of the emulsion by volume shall be 18-22.

7. The residue from the foregoing distillation shall have the following characteristics:

(a) Penetration at 77 degrees F., 100-150.

(b) Ductility at 77 degrees F., 100.

(c) Total bitumen (Sol. in CC14), 99.5% min.

(d) Oliensis test after 24 hours, negative.

The advantage claimed for such material is that it lends itself to any type of construction method, such as plant mix, traveling plant or road mix, with any kind of aggregates; that it can be used in a fine graded mixture equal to sheet asphalt grading; and that water troubles commonly encountered in the use of present types of emulsions and cutback asphalts do not hinder the mixing operation. We understand the preparation or blending of the finished product is a patented process originating with the Standard Oil Company. It so happens that the asphalts being used in the preparation of this product for our use are from sources that have proven highly satisfactory in our work using other grades of liquid asphaltic materials. While a considerable amount of this material has been placed this season with aggregates and mixtures recommended by the laboratory as a result of stability determinations, we are still adjusting our requirements as seem necessary from time to time, that we may be certain that we are securing the most satisfactory combination of materials and mixture. However, none of this work has been in place for a sufficient length of time at this date for us to arrive at a definite conclusion or make any further comment on its use.

Summary of Costs of Completed Inverted Emulsion Road

Materials purchased and work done by state forces.

Base course, from local pits, 5-inch compacted 22-foot roadway complete in place, $2,000 per mile, $0.155 per square yard.

Base prime, 22-foot roadway, MC-1 oil, .2 to .3 gallons per square yard, $0.0175 in place per square yard.

Surface, aggregate of local pit gravel and sand, 1-⅜″ thick, 20-foot roadway, $0.17 per square yard complete.

Typical finished mixture:

Passing ¾-inch screen	100%
Passing No. 10 sieve	60-80%
Passing No. 200 sieve	6-10%
Inverted emulsion	5.5-7%

During the present season Oklahoma has under way quite an extensive program of bituminous surface treatment. A large part of this is road oiling under the Maintenance organization, and also some contract work with federal and state funds.

The road oiling by the Maintenance Department consists principally of construction of an oil mat with local aggregates of the "close-graded" or "fine-graded" type and an SC-3 road oil.

Finished thickness of bituminous surface, 1 inch, 1½ inches, 2 inches and 2½ inches.

Oil Mat Completed Surface

Materials and work by state forces. Placed on existing gravel.

Base prime, 22-foot roadway, MC-1 oil, .5 gallons per square yard.

Surface, aggregate of local pit gravel and sand, 2 inches thick, 20-foot roadway, $0.15 per square yard complete.

Typical finished mixture:

Passing ¾-inch screen	100%
Passing No. 10 sieve	40-70%
Passing No. 200 sieve	6-13%
SC-3 oil	4-7%

Where oil mat or cutback surface is to be placed on a subgrade or base that is considered as having satisfactory stability, a prime application is usually made with an MC-1 oil. After this prime application has cured sufficiently, which is usually one or two days, depending on the weather conditions, the aggregates are added, the slow curing oil applied and manipulated with patrol blades until satisfactorily mixed. Traffic is permitted to go through the work as necessary. Since the traffic provides the necessary compaction, with exception of the edges, it has been found necessary in most cases to compact by rolling only the edges or approximately the outside third of the width of the roadway. In this type of work only a few days are necessary to secure a very satisfactory surface.

The other work in progress under the Maintenance Department wherever it is found that the subgrade and/or base is not adequate to support the proposed surface treatment, a stabilized base course is placed. Base material is secured in practically all cases from gravel deposits locally available, and blended with the necessary binder and other materials to meet the requirements of the specification mentioned heretofore. On such base course, which does not necessarily provide a satisfactory wearing course for a long period, a light mat with SC-3 road oil or a fine-graded aggregate type surface with MC-2 cutback asphaltic material is being placed.

Contract work of bituminous surface provides in all cases for the construction of stabilized base course finished by sprinkling and rolling, the application of a prime oil of the MC-1 type and usually an inch and a half "close-grade aggregate" type surface using an MC-2 cutback.

An interesting type of construction somewhat new to us in Oklahoma is now getting under way, but does not provide as yet sufficient information to be of value other than to make mention of its being placed. This is what has been recently termed "sub-oiling." This is being undertaken in a section of the state in which the soil is such as to be very difficult to maintain as a dirt road, is too sandy to permit successful graveling, and no gravel is economically available, thus providing what we consider an ideal situation for sub-oiling or a heavy oil mat made with existing materials. The average soil on this road is a typical A-1 with a plasticity index of 1.5, passing the 40 mesh 94.8%, and passing the 200 mesh 40%.

It so happened that when this particular work was started the extremely dry weather had eliminated all moisture from the material to be treated. The water supply situation, in general, was such that it was impossible to arrange for any water for use prior to application of the oil. Tests in the laboratory indicated that approximately 10 per cent moisture in the soil provided the fastest and most thorough dispersion of the oil. We, therefore, doubted seriously the success of the work under these conditions, and are now pleased to find somewhat satisfactory results up to this time. The oil used is SC-2 material, and is being placed in the initial application at about 5 to 6 inches in depth.

The sub-oiling machine was constructed by the highway department and consists of a 600-gallon oil distributor mounted on an old motor patrol chasis. The oil is applied through teeth suspended in two rows from the blade circle. The teeth are spaced at six-inch intervals and staggared to give three-inch intervals between lines of application. The total width of application is eight feet. The unit is drawn by a 60-horsepower tractor. It was found that the capacity of the machine was not sufficient to place the full quantity of oil at the rate of approximately one gallon per square yard per inch of depth and additional trips with the distributor were necessary applying additional oil at higher levels to complete the final quantity. At this time the first application is being made at about five inches below the finished surface. The capacity of the equipment has been increased by placing an additional oil tube behind each tooth and the full quantity of oil required is being placed in two applications or trips through the road.

This road is so located that it is necessary to permit traffic to use the road while under construction. The fact that the scarifying and breaking up of the road bed in this fine, granular material during dry weather, made it almost impossible for traffic of any description to get through the road and presented a problem for those in charge. The practice, therefore, was developed of pulverizing the subgrade to the necessary depth and when this was accomplished, blading out this loose material. This was bladed back into the road and shaped for the distance of the round to be made by the oiler just prior to the machine reaching the section. During, and immediately following the application of the oil, a "split log" type drag maintained a smooth surface and provided the only means of compaction which could be satisfactorily utilized. By making the last application of oil at about two (2) inches from the surface, a large percentage of particles are soon coated under the "whipping" of traffic and some of the other loose material is blown, or whipped off so that it is found within a very few hours that the average vehicle has no serious difficulty in getting through. It is believed that it will be necessary, when it rains and more rapid dispersion of the oil takes place, to provide blading and manipulation of the then existing surface to provide a uniform section upon which additional material to "blot" the surplus oil can be bladed in from time to time until final dispersion has been effected and a satisfactory surface obtained.

We believe that this type of construction in sections of our state will be an economical means of taking care of traffic and will also be an initial step in stage construction that will later, or, at this time as may be necessary, provide a stable and adequate base course for additional and higher type surface treatments as the traffic conditions may require.

At this date sufficient data is not available to estimate completed cost of this work.

Due to the fact that the existing highway organization has found very little of value in the records to permit the study of bituminous work which has been placed in the past, thus enabling us to benefit therefrom and improve the design and quality of materials in present construction, an accurate and permanent record is now being made of all such improvements. This will include any prelimiary study and analyses of the subgrade soils, a record of the base course materials and the thickness as it exists or may be completed, a screen analysis of the surfacing aggregates and the type and amount of asphaltic material used in the mixture. Test reports covering all liquid asphaltic materials used in the work are furnished those in charge and are a part of the completed record. The field forces furnish all the necessary records of construction details and the rate of application of the asphaltic material. A record of all failures, special maintenance, and general condition and behavior of the surface from time to time will be made and reported to provide a continuous and complete record.

To facilitate the handling of materials from the several refineries furnishing the asphaltic products, the Materials Testing Laboratory has inspectors at the refineries to make the necessary tests on the products as produced and to furnish test and shipping reports to the field engineers using the materials. Other copies are forwarded to the Oklahoma City records.

Our refinery inspectors, in addition to the routine sampling and testing, are assisting in research work in asphaltic materials. During their field assignment they are endeavoring to learn all they can as to the characteristics of the original materials, together with methods of refining and special processing which may effect the quality of the finished products.

Samples of each shipment of all asphaltic products being used in construction are forwarded to the laboratory for check tests and storage for future reference. This provides, for use in the laboratory, an ample supply of all such materials, and will enable us to make further tests or studies of the individual products in connection with any failures that may develop in the completed work over a long period of time, that seem to be due to characteristics of the asphaltic material. The supply will also permit us to carry out further research studies and investigations that may seem desirable as we learn more of their behavior, and to conduct additional tests for quality of same as may be introduced by other investigators during the next few years.

We have in Oklahoma many sources of materials which have, from time to time, been offered for use in bituminous work. We feel that the several producers usually supplying us are furnishing very satisfactory material, but with the frequent offer of quotations on new sources, we feel we have a complicated problem confronting us. Largely due to this condition, we have for some time been conducting extensive research which may enable us to develop information and test procedure which will permit us to determine definitely any quality characteristics in products proposed or submitted for use, as well as those that are now being used in our work.

Up to the present time we have made the usual combination of tests on innumerable sources of materials, from Mexican asphalt, to residues from local fields which had no apparent quality for road building work. While many of these tests are yet to be made on some of these materials, we have not, so far, been able to find any outstanding variation or combination of characteristics which apply directly to materials which, from past experience or other information, are considered to have the necessary, desirable quality characteristics. We expect to continue this activity in the laboratory on outside materials as well as on those that are being used in our construction work, in the hope that we will be able at some future time to know or be able to distinguish definitely between products which will give us satisfactory service and those which will not.

DEVELOPMENTS IN BITUMINOUS DESIGN AND CONSTRUCTION IN THE INTERMOUNTAIN STATES

By W. D. Ross, Materials Engineer,
U. S. Bureau of Public Roads, Denver, Colorado

Only ten short years ago travel over the main highways through the intermountain states consisted of fighting the dust hazard in heavily traveled sections and trying to maintain a reasonable degree of progress toward our destination over the loose gravel and corrugations for the remainder of the trip. Only when approaching the larger centers of population did we encounter pavements which would permit us to relax with a feeling of security. Today the traveler over these same highways completes his trip on a smooth, dustless surface at speeds controlled only by his conscience and the ability of his car. The old graveled road is about as attractive today when compared with our modern oiled roads as the bathing beauty of the gay 90's is when compared to our present day models. We should all be, and I believe we are, deeply thankful for these wonderful developments leading towards a fuller enjoyment of our national progress.

The description of principal types of bituminous surfaces being used in this region are described under the state in which they are used. First the forest and park work done by District No. 3 of the Bureau of Public Roads is given, followed by the states of Arizona and California, Colorado, Idaho, Montana, Nevada, New Mexico, Texas, Utah, and Wyoming.

Bureau of Public Roads Construction In Forests and National Parks of District No. 3

The construction of oil roads was first undertaken by District No. 3 of the Bureau of Public Roads in 1928. The early work was done by road mix methods, using dense graded aggregates and asphaltic oil similar to our present SC-2. This was followed by plant mix work using the same materials or slightly heavier asphaltic oils. Owing to the high elevations at which these roads were often constructed and the mountain locations encountered it was found that the plant mix fitted into the picture exceptionally well. For plant mix, mountain showers caused a minimum of delay. Service to traffic was much better with plant mix for, in many cases, detours were out of the question. Heavier asphaltic oils could be used without feeling, to such a decided degree, the effect of the cold nights. However, these dense graded aggregates, mixed with SC oils, seemed to be exceptionally susceptible to the ill effects of moisture and the melting snows in the spring, together with freezing and thawing, developed failures which caused expensive maintenance operations. In striving to overcome this the Bureau constructed several plant mix jobs using MC-4 with the dense graded aggregate, and sealing the surface with RC material and chips. These jobs have proven to be very stable and have shown distress only where subgrade weakness is indicated. Along with this work three contracts were undertaken using an open graded aggregate with an RC-3 cutback. One of these jobs was constructed by regular plant mix methods, one by road mix methods using blades for mixing, and one with the traveling road mix machine, the method of mixing being left to the contractor's selection. One of these jobs, the first to be constructed, was 1½ inches thick. This was plant mixed and laid with an Adnun Black Top Paver. The mat looked so thin that apprehension was felt as to results if laying by blades were to be followed. The other two jobs were, therefore, designed for a 2″ thickness. This type has proven more costly than the dense graded type and has failed to show any definite advantages even if costs are considered to be equal.

In Colorado, Wyoming, New Mexico, and the Black Hills of South Dakota the Bureau of Public Roads has completed some 460 miles of oil road construction, 120 miles being of a temporary surface treatment type, 140 miles of road mix, and 200 miles of the most recent type of plant mix with dense graded aggregate and MC-4 which cost from $5,000 to $7,000 per mile for a 2½″ mat; 38 miles of open graded aggregate with RC-3 binder cost $4600 to $6000 per mile for 1½″ to 2″ mats. The selection of the open graded type has, in each case, been made where fines of suitable quality were lacking. In both of these types the base is first primed with MC-1 at the rate of from one-fourth to one-half gallon per square yard. Where the open graded type has been used, special studies have been made of the efficiency of the seal coat. A double seal has not yet been resorted to. Indications are that satisfactory results can be secured by the following method. After the final spread of the mixture is made it is rolled once over and immediately covered with an application of the minus 10 material produced by the crusher and which is called choker material. This choker material is spread at the rate of from 10 to 12 pounds per square yard and rolling is then completed. After being opened to traffic for two weeks or more a seal coat of one-fourth gallon RC-3 and 15 to 20 lbs. of chips between three-eighths inch and No. 10 is applied per square yard. The choker material fills the surface interstices and plugs the small holes and cracks in the surface of this open mix. Tests with permeability equipment indicate that leaks of 6000 cc per 10 minutes are reduced to a negligible amount by the use of this choker material and the action of traffic. Some excessive leaks have been found along the edge of the mat which traffic has avoided and these places have been touched up with approximately one-tenth gallon per square yard of RC-3 prior to placing the final seal coat.

The use of a mechanical spreader or finisher such as the Adnun and Jaeger machines have given such satisfactory results that an additional incentive for plant mix has thereby been created. On two different jobs in Colorado the results secured with a mechanical finisher have been compared with results on the same jobs where the usual method of laying was used. These comparisons were made using a car equipped with a roughometer measuring spring deflections. In each case the results secured with the mechanical finisher were from 30 to 50 percent better than when the regular method of spreading was used.

Low Cost Bituminous Surfaces in California and Arizona

History:

Previous to 1926 low cost bituminous surfaces in California involved little more than light surface applications of liquid asphaltic materials. Some job variations involving rudimentary road mixing with fuel oils had attracted attention to the possibilities of that type of work, and in that year the State Division of Highways, in conjunction with the Bureau of Public Roads, started a series of investigations from which the California type of road mix developed. Records of the investigations were published by the State Division of Highways in 1927 as "A Progress Report of a Cooperative Investigation of Intermediate Road Types," prepared by W. N. Frickstad of the Bureau of Public Roads and C. L. McKesson of the California Department. Somewhat later developments are recorded in a paper prepared for the 1927 convention of the American Association of State Highway Officials, by T. E. Stanton, State Materials Engineer.

The promising features of these earlier types of road mix led to an immediate increase in their use and constant improvements in construction methods and materials. In the earlier types, lighter road oils corresponding to SC-1 and SC-1A were used. These gave a fair measure of success under ideal climatic conditions and light traffic, but did not suffice for heavy traffic and severe winter conditions, for which increasingly heavier types of binder, including cutback asphalt, were developed. By 1929, liquid asphalts as heavy as SC-2, SC-3 and MC-2 and MC-3, which appeared to be as heavy as could be road mixed, were in general use. However, still heavier binders were desirable, and it also was becoming apparent that to obtain uniform surfaces, a more rigid control of aggregate grading, and quantities of asphaltic binder was necessary. The answer was obviously plant mixing, and by 1930 plant mixing processes were quite fully developed.

The increase in the mileage of low-cost bituminous surfaces in California has been continuous. The state's biennial report for 1934 shows 5,171 miles of these types in a total state highway mileage of approximately 14,000, which compares with a total of 722 miles on June 30, 1928.

The development of low-cost bituminous surfacing in Arizona has paralleled quite closely that in California; at the end of 1934, the state reported 1,379 miles of these types in a total state highway mileage of 3,043.

Present Practices and Trends:

Types of treatment in the two states consist of three main classes: (1) Penetration treatments (2) Armor coats (3) Plant and road mixes.

1. This class, used extensively in California, includes light surface applications of SC-1, SC-1A and SC-2 on unsurfaced, or

old wornout surfaced roads, and penetration treatments with heavier asphaltic binders on selected material subgrades, crushed stone base courses and the better existing crushed rock or gravel surfaces. For the former type, liquid asphaltic material is applied to the smoothed surface at rates of from ¼ to ½ gallon per square yard, usually in open application with little or no blotting. This type of treatment costs from $200 to $500 per mile. Its lifetime is approximately one season, and its use is mainly confined either to low standard roads where existing roadway material does not justify more expensive treatment or as "stage construction" where a more durable surfacing is contemplated within a short period.

The heavier penetration treatment is used where the roadway material justifies the attempt to secure a fairly durable wearing surface, or where for economic or other reasons such as possible fill settlements on new work, it is not possible or advisable to apply a more expensive surface. For this treatment, the existing surface is shaped and consolidated as much as possible by watering and rolling and the asphaltic material, usually SC-2, applied in two applications of approximately ½ gallon for the first shot and ¼ gallon for the second shot per square yard. Ordinarily the first application is allowed to penetrate not less than 24 hours, and requires little blotting. The second application has to be blotted or sanded, and will take up from 15 to 20 pounds of material per square yard. A variation of this method is to side windrow from ½ to ¾ inches of material during reshaping operations and use it to cover each application. Ultimate results of two methods show little variation, though the latter method occasions less interference with traffic. This treatment costs from $500 to $800 per mile, and on a fairly well-graded surface will produce from ¾ to 1 inch of smooth, compacted material. The Bureau of Public Roads have used this type extensively as a stage construction operation on well-selected subgrades and crushed rock or gravel bases, and intend to continue its use. Two years of life can be expected without excessive maintenance. If necessary, the lifetime can be prolonged by further applications of from ⅛ to ½ gallons of SC-2 or MC-2, according to the condition of the surface, without adding additional stone.

Arizona State has not used this type to any appreciable extent in the past. However, it is at present applying it on various projects, and the trend is towards increasing use.

2. Armor coats of two types are in general use. First, light, in which a ¾″ maximum sized clean, graded crushed material is used, and which produces a course of approximately this thickness; second, heavy, in which the maximum size of the crushed material and thickness of course is 1¼″. These types are used on older, well-consolidated bases; as wearing courses on old pavements and on new heavy slurry bases. Both types require hard stone, tough enough to stand the roller, and with a low percentage of abrasion. Clean, crushed material with a large percentage of fractured faces is required. Choice of the two types is determined by local conditions and amount of traffic.

The light type requires approximately 60 pounds of ¾″ to ½″ rock, and 20 pounds of ½″ to 10-mesh screenings, bound with ½ gallon of hot 90-95 or 95+ road oil, naphtha cutback or emulsion. Construction procedure with road oil has been to apply ⅛ gallon of the bituminous binder heated to about 325° to the consolidated base, previously primed, if necessary, with from ⅛ to ¼ gallon of SC1A or MC-1. The ¾″ rock is then evenly applied and rolled to compaction. The second application, ⅜ gallon, is then spread and covered with the ½″ material. The entire surface is then thoroughly broomed and rolled.

Fair success has been obtained from this type, excepting that the surface produced has not been sufficiently impervious under wet conditions. It is now becoming common practice to seal these surfaces with a third application of ¼ to 1/6 gallon of hot 90-95, 95+, cutback RC-3 emulsion, and 8 to 12 pounds of No. 10 to No. 200 rock chips or sand. Use of the cutbacks and emulsions for this purpose is on the increase, as more penetration and less subsequent bleeding is effected than with the hot oil.

The heavy type is similar in construction to the light type excepting that rock is used in the following three sizes and approximate quantities: 1¼″ to ¾″—86 lbs; ¾″ to ½″—27 lbs.; and ½″ to 10-mesh—15 lbs., and is applied in three applications with ⅕, ⅖ and ¼ gallon of bituminous binder, each application being thoroughly broomed and rolled. This type has shown the same lack of imperviousness to water, and a seal similar to that used for the light type is ordinarily necessary.

Costs of the light type are from $2,500 to $3,500, and of the heavy type from $3,000 to $4,000 per mile, exclusive of base. With adequate bases they are apparently adequate for a daily traffic of from 1,000 to 1,500 vehicles, and their lifetime should approximate

8 to 10 years under ordinary conditions. They appear, however, to be rather susceptible to damage by snow removal equipment.

3. Plant and Road Mixes. This class includes the Class B, C and F types, ranging from the cheapest type of road mixed natural material to expensive rigidly-controlled plant mixes. Specifications and construction operations for these types are too well known to warrant a detailed description here. It is believed sufficient to cover only the general trends in construction and particular uses.

The cheapest type of road mix is the mixing in place of native roadway material, using approximately one gallon of SC-2, SC-3 or MC-2 or MC-3 per square yard per inch of thickness. On granular soils, particularly on the disinegrated granite found in Southern California, this type of work has provided many miles of good surface. The cost has been from $2,000 to $4,000 per mile for binder and mixing, to produce a 2½″ compacted mat. Little use of this type has been made in Arizona, on account of unsuitable native material.

In the better types of road mixes crushed rock or crushed gravel, complying with fairly rigid grading specifications, is used. The common grading is 1″ maximum, 35 to 50 per cent passing 10 mesh and 5 to 10 per cent passing the 200. From 4 to 5 per cent of SC-3, SC-4, MC-2 or MC-3 is used as binder. Although for cold localities the State of California favors the use of R.O.M.C. 3 and R.O.M.C. 4. It has been found feasible to road mix these binders. California has, however, generally preferred the more rigidly controlled plant mixes, and the road mixed type is not generally used on new work excepting on projects so short as to render the installation of plant mix equipment markedly uneconomical. Approximately one-half of the mileage of mixed surfacings in Arizona is of the road mixed type, principally because numerous gravel deposits permit several setups and short hauls, and local contractors were not usually equipped with mixing plants. For these reasons, plant mixes were considerably more expensive.

The cost of the road mixed crushed aggregate mixes has varied from $4,000 to $6,000 per mile, exclusive of base, for a 2½-inch compacted mat. The lifetime of a well-sealed project, properly constructed, is probably at least ten years, and the surface should carry up to 1,500 vehicles daily. Disadvantages of the type have been the impossibility of control of thickness, aggregate grading, and the amount of binder; also the type does not permit essential control of moisture content. These disadvantages and the inability to use heavier binders in road mixes have resulted in the trend towards plant mixing.

Aggregate gradings for plant mixes in the two states are generally identical with those stated for road mix. Grading is further controlled by requiring segregation of the aggregates into at least two bins, above and below 3-mesh, and weighing of the aggregates into the mixer. Limitation of moisture to a maximum of one per cent generally forces the use of a drier for the aggregates. Pug mixers are usually specified, with a mixing time of not less than 30 seconds, after all the ingredients are in the mixer. Quantities of asphaltic binder are computed from surface areas and from 4 to 6 per cent are used. Asphaltic binder is generally MC-4 or MC-5, or R.O.M.C. 4 and 5, although occasionally SC-4 is used.

Typical costs of plant mix surfaces range from $4,000 to $6,500 per mile for a 20′x2½″ compacted mat. In general, they are slightly more expensive than road mixes, but the additional costs are believed justified by the certainty of obtaining a more uniform and durable product, with bituminous binder of more weather-resistant qualities than those possessed by the lighter liquid asphalts demanded by road mixing methods.

In both road mix and plant mix types specifications for laying are detailed and a tolerance of not over ¼ inch variation from a 10-foot straightedge permitted. Rolling is required on both types.

It will be noted that the tendency during the past ten years has been towards increasingly heavier types of binder. With blade-laying of plant mixed material the use of an asphalt heavier than MC-5 has been found impractical without side forms and paving machines. The result advent of such machines as the Adnun and Jaeger pavers opens the possibility of much heavier binders being utilized. The Bureau of Public Roads now has under advertisement two plant mixed projects in which 90-95 road oil is specified and self-powered spreading machines required. Mixing and laying temperatures comparable to standard Class 1 asphaltic concrete are of course necessary.

Seal and Prime Coats

Prime coats consisting of one-fourth gallon per square yard of MC-1 or MC-2 (occasionally SC-1A) are ordinarily placed on the bases for all plant mix tops, unless they have recently been treated with bitumen, and are quite often applied for a mixing table on road mixes. The costs of these are from $200 to $300 per mile. These costs are included in the typical costs given for the various types.

The use of seal coats on road and plant mixes, except on the cheaper types of road mixes, is common practice. These seals vary from one-tenth gallon per square yard of MC-4 or 5 without screenings, to one-fifth or one-fourth of a gallon of hot 95% or RC-2 or emulsion, covered with 15 pounds of ⅜-inch to No. 10 screenings. The one-tenth gallon treatment is ordinarily effective only for semi-arid conditions, but can be placed very shortly after placing the surfacing, and costs only $100 to $150 per mile. The heavier seals, including cover stone, cost from $500 to $800 per mile, and are placed at any time after the surface has had two weeks' traffic compaction. It appears advisable to seal at least within a year after placing the surfacing.

Bases and Subgrades

On well-stabilized and compacted subgrades a minimum combined thickness of 6 inches base and wearing course is a general requirement. Bases vary with localities, but crusher-run aggregates, passing a 1½-inch sieve with 10 to 15 per cent of No. 200 material, predominate. Increasing use is being made of the so-called "Slurry Base." A typical specification for this calls for 2½-inch maximum size crusher run rock uniformly graded with 7 to 14 per cent of No. 200 material. The rock is stored in two bins, splitting on the 3-mesh size. The material is mixed in a pugmill with not over 15 gallons of water per ton of aggregate, and then placed with spreader boxes. After placing, sufficient water is applied to cause flushing and the base is then rolled until no more compression is possible. These bases have proven very successful.

On clay subgrades, bases up to 12 inches in thickness have been found necessary. It is becoming common practice in both states to sample and test representative portions of the subgrade before starting surfacing work. Ordinarily, highly capillary subgrades, or those containing excessive quantities of colloidal fines, are stabilized by the addition of granular material or by substantially increasing base thickness. During the past three years some city and county and a few state projects have been built where diluted emulsified asphalt is used as a stabilizer and water repellent. This treatment consists of blade-mixing diluted emulsified asphalt into the subgrade to a depth of from 4 to 6 inches.

The amount of emulsified asphalt used is about 15 per cent of the No. 200 material. If the subgrade is entirely deficient in granular material, varying amounts of this are added to increase stability and reduce the No. 200 material to 20 or 25 per cent of the total, and correspondingly reduce the amount of emulsion necessary. This treatment shows promise, but it is likely to be more costly than the addition of subbase material unless the latter is not locally available. The Bureau of Public Roads recently advertised a project which included three sample types of this work. The borrow subgrade material contained approximately 60 per cent of 200-mesh. Three test sections are included, on one of which the natural material is to be mixed to a 6-inch depth; one to a 3-inch depth without addition of granular material. On the third portion 1½ inches of ½-inch natural sandy gravel is to be mixed with 1½ inches of the subgrade, and the resulting three inches treated. A light wearing course consisting of three-tenths to one-half gallon of emulsifiied asphalt covered with 20 pounds of ½-inch gravel screenings per square yard is provided for the three sections.

Colorado

The State of Colorado did no bituminous work of the so-called low cost type prior to 1928. At that time the state highway system was approximately 9,120 miles in length, 340 miles consisting of Portland cement concrete or other high type pavement; 3,700 miles were surfaced with gravel, sand clay or other local materials, while 800 miles were graded and drained with the remainder of the mileage unimproved. The early construction undertaken consisted of road mixing the previously constructed gravel surface with road oil approximately our present SC-2. These mats were 2½ to 3 inches thick. As this type of construction developed the plant mix was introduced, using the same type of oil with the same quality and grading of aggregate. Also new gravel was added for the road mix work instead of securing it by scarifying the previously constructed gravel surface or base. In one district of Colorado plant mix jobs and road mix jobs were both constructed the same year. The district engineer in charge of this work required that the new gravel for the road mix work be placed in a windrow on the road by first windrowing one-third of the total gravel to be placed for a distance of not less than one mile. This was followed by adding to the windrow the second third of the total requirement and then the final or last third was added in the same manner. This added little, if any, additional cost to the contractor, the principal difference being that each load was spread over a distance three times as great as where the entire windrow is placed in one operation. By this means the nonuniformity of the pit is compensated for to a considerable degree. After completing both the plant mix and road mix jobs, samples of the completed oil mat were lifted from the road, the oil extracted and the grading of aggregate determined. It was found that better unnformity in aggregate grading had been secured on the road mix than with the plant mix.

Oil road construction in Colorado amounted to 14 miles for 1928, 56 miles for 1929, and 107 miles were added in 1930. The average cost for this early work was approximately $2,000 per mile, not including the addition of new aggregate. In 1934 Colorado constructed 343 miles of 1-inch mat with state forces, using road mix methods with SC-3 oil. The average cost of this work was approximately $1,155 per mile. A minimum cost of $860 per mile was had where no new aggregate was required and a maximum cost of $1,800 per mile was had where all new aggregate was used for the oiled mat. The state expended approximately three-fourths of a million dollars last year in this type of construction and have programmed for this year approximately double that amount.

This thin mat of low cost permits rapid transition of gravel roads to dustless oil surfaces where mileage is great and funds limited. The use of SC-3 oil permits of the simplest operations in scarifying, relaying and recompacting these surfaces when failures develop. Corrugations are believed to be more numerous than where cutbacks are used and the continued use of slow curing material in preference to the cutbacks is contrary to the general trend in the mountain states, but Colorado has not yet seen fit to make the change to the cutback types.

Bituminous Work in the State of Idaho

The growth of the oiled road mileage has been the most outstanding development in the construction of the state highway system of Idaho. In 1927 but 80 miles out of a total of 4,200 miles in the state system were oiled, whereas at the present time approximately 1,700 miles of a total of 4,600 miles have been oiled.

With excessive ravelling and breakdown of the untreated gravel and crushed rock surfaces, and with mounting maintenance expenses, the state in 1927 initiated a program of road mix oiling on routes where traffic did not justify the more expensive types of pavement and where a comparatively low-cost type of dustless and durable surface was necessary. This type of work superseded a skin-surface treatment adopted experimentally from Oregon in 1926, and was based upon observations of the road mix type of construction under way in California. As Idaho contractors were not equipped for this type of work, the state initiated the oiling with force account crews.

Initial construction consisted of a harrow and blade-grader treatment of existing surfaces with a 2″x18′ oil mat using a medium grade road oil corresponding to an SC-2 classification. Costs of this type of construction approximated $2,000 per mile.

As the yearly construction of the road mix surfaces proceeded, specifications were altered so as to require a dense graded aggregate, maximum 1″ size, with a 2½″x20′ oil mat with 5″ edges. It was found that climatic conditions, particularly in the northern part of the state where the annual precipitation is heavy, were not suitable for SC-2 oil and at the present time an SC-3 or MC-3 oil, in general, is being used with an MC-3 or MC-4 oil with screenings for the seal coat. Recent contract costs for this type of construction approximate $3,000 per mile.

Since 1930 a variation of the above type construction has been used to a great extent with the introduction of plant mix construction also of the dense graded aggregate type. MC-3 or MC-4 oil is used as a binder with an MC-1 prime coat and an MC-3 or MC-4 oil with screenings for the seal coat. The typical section used for this work is the same as for the road mix type. A closer control of the mix is possible in this type of construction at a slightly higher cost than that given above for the road mix type.

Failures of the above mentioned road mix and plant mix types have been noted where inadequate bases were in place. Such conditions are now being corrected by the construction of base courses of at least 6-inch compacted thickness with additional subbase material where conditions are poor. Another source of failure has been noted due to softening of the edges of the oil material on account of inadequate side drainage of the base. This condition is being corrected by the use of full width base and subbase construction or by replacing the existing earth shoulder with material sufficiently granular to prevent trapping of either surface or capillary water under the edges of the oil mat.

Oiling of the balance of the state's system will probably proceed with similar specifications and design standards to those noted above as the design and construction methods crystallized in the state's specifications are producing good results.

Forest Roads

The bitutminous work on Forest Highway routes has been, in general, comparable as to types and methods to that done by the State Highway Department. Only a limited amount of this work has been done on forest routes.

Bituminous Work in Montana

On December 31, 1928, Montana's State system, which was then practically coincidental with the Federal Aid system, was 4,673 miles in length. Of this mileage, 53 miles were paved with bituminous macadam, or high type paving, and 1,831 miles with crushed gravel, on 30 or 40 miles of which the maintenance forces had placed a road mix or had applied a surface treatment of hot 95+ or grade E asphalt and stone chips. Oiling started as a major construction activity in 1929, when 106 miles of road mixed surfacing were built. The oil used was of the type now classified as SC-2, and traffic was depended upon for compaction. Ordinarily, the combined thickness of base and top was 6 inches, which did not prove to be sufficient on some of the bad soils, and was substantially increased in subsequent designs. Two hundred and eighty-four miles of road or plant mix were added the following year, and every year since a substantial mileage of this type of work has been done, as well as a large mileage of surface treatment by the maintenance forces. The latter ordinarily consisted of the application of .3 to .4 of a gallon each of SC-2 and SC-4 oil, each application covered with one inch minus crusher-run aggregate. By December 31, 1932, there were 512 miles of these surface treatments in place and 576 miles of Class B or C surfacings. On December 31, 1935, there were 1,072 miles of surface treatments and 2,117 miles of Class B, C or F, and a large program is under way this year. A variety of types of asphalt have been used. At present SC-3 and MC-2 predominate, in the road mixes, RC-3 or SC-4 in the plant mixes and seals, MC-1 for prime treatments, and SC-4 for the light surface treatments. The mixes are sealed and roller compaction is employed in all cases. Bituminous surfacings of these types have been built for traffic up to 1,500 or 2,000 cars per day.

During the past four or five years Montana has made extensive use of heavy pit-run gravel sub-bases, which are plentiful in many parts of the state. On bad soils from 6 to 12 inches of this material are placed, frequently at a cost in place of only 50 or 60 cents per cubic yard. A blanket of fine crushed gravel is usually placed, as the pit-run surfaces are too rough for comfort.

Due to the public demand for dustless roads, as well as the economy obtained by conserving gravel, and to the further engineering advantage of testing the behavior of the base when normal evaporation is cut off by a bituminous seal, the Montana department appears to be quite in favor of stage construction of bituminous surfacing. A considerable mileage of that type of work, quite similar to the state maintenance work mentioned above, except for substitution of MC-1 for SC-2 in the first application, is included in the surface-treated mileage above mentioned. The cost, including watering and rolling and careful preparation of the base, was about $1,500 per mile, about half of which was for asphalt. The state expects such treatments to serve traffic for two years, by which time the life of the treatment will be gone and subgrade weaknesses will have been detected and corrected. The final surfacing will usually be a Class B, C or F mix about 2½ inches thick.

There have been two rather unusual types of bituminous work in Montana: First, some Class F work with RC cutback instead of MC; second, bituminous treatments of scoria. In the RC Class F work a so-called "dense" grading was used, though the No. 10 material was limited to 35%, and the No. 200 to 8%. The material was deposited through spreader boxes, and was rolled after only a short interval. Apparently most of the naphtha came out, though no attempt was made to aerate it before spreading. This project was located between Helena and Great Falls. A Forest Highway project was awarded the same year on the Yellowstone Trail, northwest of Missoula, under similar specifications. On the latter project, short experimental sections using 5, 10, 15 and 20 per cent of material passing the No. 10 sieve was set up during construction. All of the experimental sections were satisfactory. The scoria treatments were discussed by Professor Conkling at last year's conference.

Montana's largest single oiling operation, in fact the largest in the West, was that done in 1934 and 1935 under PWA Docket 1833. This docket provided for 15 road mix and one plant mix projects, a total length of 704 miles. The typical section provided for a Class B mix with SC-3 liquid asphalt, 22 feet wide, on bases of pit-run or crushed gravel, and a total minimum thickness of base and top of 6½ inches. On some sections an MC-1 prime was used; where the prime was omitted, a seal coat of one-tenth gallon of RC-1 was applied. It was generally agreed that the light seal was noticeably beneficial on projects where the mix was too lean, but was not mandatory where an adequate amount of oil was used in the mix. The 22-foot width of oil met with everybody's enthusiastic approval. The total cost of the 704 miles was $1,955,462. On such a large operation—actually "mass production"—the unit costs were low, and the results have been highly gratifying.

Low Cost Bituminous Surfaces in Nevada

Prior to 1927 improved road surfaces were untreated fine crushed dense graded gravel, except a limited mileage of high type surfaces in the vicinity of the principal towns. A combination penetration and road mix treatment with light asphaltic oil had been used on a 10-mile section of loose sand with fair success, and a penetration treatment had been used on one 3-mile section without success. It was apparent that light penetration treatments could not be used generally throughout the state because of lack of water and suitable binder to obtain a thoroughly bonded surface free from loose spots prior to applying the surface treatment.

The first standard road mix asphaltic type, Class B-1, was laid in 1927. At present there are around 1,900 miles of this type, of which about two-thirds is on the Federal Aid system and the remainder is on the National Forest Highways system and on Federal lands highways. The aggregate is local crushed gravel fairly well graded from 1″ down to minus 200. Specifications have been written to permit the use of pit-run material without scalping to obtain fractured surfaces. Occasionally it has been necessary to waste a portion of the aggregate passing the No. 10 sieve, but in no case has it been necessary to add sand or dust. SC-2 asphaltic oil has been used on all except a few projects where MC-2 has been used. In the beginning the plans called for a compacted thickness of 3″, but for the past few years 2½″ has been specified. The cost of this type 20 feet wide has been around $3,500 per mile including the aggregate. Up until about 1930 very little consideration was given variations in the subgrade material, and the base consisted generally of a 3″ compacted thickness of gravel. Since 1930 careful attention has been given the subgrade and where analysis have indicated the subgrade soil doubtful or poor, a subbase of pit-run gravel 6″ to 1″ thick has been used.

In the vicinity of Lake Tahoe decomposed granite has been used for the aggregate. This material, after placed on the road, breaks down to such sizes that practically all will pass a No. 3 sieve and about 5 per cent pass a No. 200 sieve. The use of this material with MC-2 asphaltic oil has given excellent results.

The life of this type with traffic from 50 to 500 vehicles per day is probably 8 to 10 years, but there have been failures after a year or so of use due to poor subgrade, capillary moisture, unsuitable aggregate or an excess of asphaltic oil.

Replacement of the road mix type started about two years ago on sections which had failed, or sections where the width, grade or alignment had become obsolete. In general, replacement has been with the plant mix dense graded type 20′x2½″ using MC-3 or 4 asphaltic oil. It is placed on a 22′x4″ waterbound plant mix crushed gravel base. The cost of the surface course 20′x2½″ has been around $5,000. On these replacements the old road mix surfacing has been salvaged and used on the shoulders. This type has proven more uniform and substantial than the road mix, but a great deal more care and skill are required to obtain a smooth riding surface. On two short sections 95+ asphaltic oil has been used with a machine finish. On these sections smooth riding surfaces were not obtained due either to use of the wrong type of finishing machine or improper operation of the machine. Plans and specifications requiring the use of 95+ asphaltic oil on an 8.5-mile section have been prepared. These specifications require separating the aggregate into four bins, and a machine finish. It is hoped to develop along these lines a type better than the usual plant mix, but still considerably below asphaltic concrete in cost.

The open graded road mix type, maximum size 1½″, using emulsified asphalt as the binder, has been used to a limited extent in the towns both for a retread on old high type surfaces and on new pavements with rock bases. This has been successful, but is expensive because of the high cost of the aggregate.

New Mexico

The State of New Mexico did no bituminous work of the so-called low cost type prior to 1928. At that time the State Highway system was approximately 9,138 miles in length, of which 75 miles were of high type pavement, 1,935 miles surfaced with gravel or selected material, 980 miles graded and drained, with the remaining mileage unimproved. The early construction undertaken in New Mexico consisted of road mixing by state forces. Aggregates were scarified from previously constructed bases or new gravel was added. The oil used was approximately our present SC-2. Mats were constructed to a depth of 2½ to 3 inches. This work proved quite successful and in 1929 plant mix work by contract was undertaken using oil and aggregate as required for road mix work. Costs for this plant mix work were about $5,250 per mile as against $4,360 for the road mix done by state forces. The results of the two methods gave no indication of superior quality for one method over the other. Following the use of this type for a few years, the state undertook a rather extensive program of construction, using what is called locally "single shot," "double shot" and "triple shot" bituminous treatments. The work is all done using asphalt of 210 to 250 penetration. The single shot consists of an application of asphalt of ½ gallon per square yard covered with chips between ¾ inch and No. 10 at the rate of one cubic yard to 50 square yards, followed by thorough rolling. The double shot consists of a first application of ¼ gallon per square yard which is covered with chips between the ¾ and ½ inch at a rate of one cubic yard to 65 square yards. After rolling, a second application is applied consisting of .2 gallon per square yard covered with chips between ½ inch and No. 10 at the rate of one cubic yard to 130 square yards. The triple shot consists of a first application of .4 gallon per square yard covered with 1½ to 1 inch chips at the rate of one cubic yard to 33 square yards, and is only lightly rolled. It is then given the second application consisting of .6 gallon per square yard covered with chips between ¾ and ½ inch at the rate of one cubic yard to 66 square yards, and is then thoroughly rolled. The third application consists of .3 gallon per square yard covered with ½ to No. 10 chips as directed by the engineer, one cubic yard for each 60 square yards is produced and the unused portion is stockpiled for maintenance.

Costs for the single shot work has averaged approximately $1,700 per mile, that for the double shot approximately $1,775 per mile, and the triple shot approximately $3,470 per mile. Riding qualities secured in this type have not been as good as for the jobs where laying down is done by blades and, although the jobs are giving satisfactory service, they have shown no definite advantages over mixed types of comparable cost and, as a result, this type has not been included in the proposed work for 1936.

In 1934 and 1935 two contracts were completed using open graded aggregates and RC-3, both being road mix. Difficulties were encountered in securing an adequate seal on these jobs and on one of them considerable distress was shown this year which was attributed to moisture penetrating to the base due to melting snow on the shoulders during the winter and spring. The cost of this work was $6,666 per mile for a 2½″ mat and $4,266 per mile for a 1½″ mat compared with a cost of $4,080 per mile for a 2½″ dense graded mat. The cost and quality considered, this type seems indicated only when fines for a dense mat are of unsuitable quality and their elimination is required or when local materials are such as to indicate economies through the use of the open graded type.

Texas

Figures for this state's highway system were not readily available for the year 1928, so the figures covering the Federal Aid Highway system of Texas are given. The Federal Aid system consisted of 11,400 miles, of which 660 miles were of high type pavement, 620 miles bituminous macadam, 527 miles water-bound macadam, 3,000 miles of gravel or local material surfacing, and 800 miles graded and drained, with the remainder unimproved.

West Texas has constructed many miles of so-called penetration macadam during the past several years, and the results secured have been very satisfactory. It is the practice of the State Highway Department to leave many of the details of construction to the division engineer, which need to be varied slightly to meet local conditions. Grades are usually constructed to a minimum width of 36 feet with wide and very flat slopes. The possibility of driving over the shoulder and in and out of the ditch with ease and safety has resulted in this section being frequently referred to as the "In and Out" section. Base construction is from 10 to 12 inches compacted thickness and two feet wider than the surface course. Gravel, caliche, or a combination of these are used in the base construction. This compacted base is primed with RC-4, which is essentially an MC-2 with a viscosity of about 150 sec. at 122 F., at the rate of from .3 to .5 gallon per square yard. This prime coat is usually applied several months in advance of the surface course. Surface courses of this so-called penetration macadam are of similar construction to the single, double and triple shot used in New Mexico, the work in New Mexico having been undertaken by that state after a study of this type of construction in Texas. Five types are used extensively in Texas and are known as "Maintenance Seal Course," "Single Penetration," "Light Double Penetration," "Heavy Double Penetration" and "Triple Penetration." Asphalt of the 210 to 250 penetration grade is used and appllied at temperatures from 250 to 350 degrees F. Crushed gravel or stone chips of the specified sizes are spread uniformly and rolled. The "Maintenance Seal Course" consists of .3 gallon of asphalt spread on the primed base and covered with 1 cubic yard to 100 square yards of chips from ½ inch to No. 10 or No. 20 sieve. The "Single Penetration" consists of ½ gallon asphalt spread on the primed base and covered 1 cubic yard to 50 square yards of chips from ¾″ to No. 10. The "Light Double Penetration" consists of ¼ gallon asphalt spread on the primed base and covered with 1 cubic yard to 50 square yards of chips between the 1″ and 1¼″, followed by ½ gallon of asphalt per square yard, and an application of ¾″ to No. 10 chips at the rate of 1 cubic yard to 100 square yards. The "Heavy Double Penetration" consists of .3 gallon of asphalt spread on the primed base and covered with 1 cubic yard per 40 square yards of chips between the 1¼″ and ½″, followed by .6 of a gallon of asphalt per square yard covered with 1 cubic yard per 80 square yards of chips between the ¾″ and No. 10. The "Triple Penetration" consists of .4 gallon of asphalt per square yard applied on the primed base and covered with chips between 1½″ and 1″ at the rate of 1 cubic yard to 24 square yards. This is followed by an application of .6 gallon of asphalt per square yard and covered with chips between the 1″ and ½″ at the rate of 1 cubic yard to 48 square yards. This is followed by an application of .3 gallon per square yard of asphalt and covered with chips passing the ½″ with dust removed at the rate of 1 cubic yard to 72 square yards. Critical points in this type of construction seem to be a light rolling of the chips in each course before the asphalt is applied. This sets the chips in place. Another important point is dividing the top course chips on a ¼″ screen. That portion retained on the ¼″ is applied first and thoroughly rolled and the portion passing the ¼″ is then applied for final cover.

The engineers and construction crews doing this type of work in Texas have developed the sequence of operations with the various details of operation to a high degree of perfection. The result is a very satisfactory surface which can be constructed with a minimum of interference to traffic and at a comparatively low cost. Costs on this work are not at hand, but it is understood that Texas costs are somewhat lower than those in New Mexico for similar work. In New Mexico the approximate costs per mile, not including the base preparation or prime coat, are for single, double and triple shot jobs $1,700 to $1,775 and $3,470 respectively.

Bituminous Work in Utah

Construction of state highways in Utah previous to 1927 consisted entirely of untreated gravel or crushed rock surface except for a relatively small mileage on the important roads in the more densely populated areas where concrete pavements had been placed. The oiling program was initiated in 1927, when a relatively small mileage was constructed by road mixing the material in place. For these earlier projects a medium road oil, approximating the standard grade SC-2, was used as binder with no seal coat. Since 1927 steady progress has been made in this type of work, with the result that at the end of 1935 approximately 1,150 miles of the total Federal Aid system of 2,004 miles have been surfaced, either by the road mix or plant mix methods.

At the present time the commonly used type of construction is the road mix method, utilizing an SC-3 oil binder with a seal coat of MC-3 or MC-4 oil, covered by ½″ to No. 10 screenings. An MC-1 prime coat is required where machine mixing is used. There has, however, been constructed a considerable mileage of the dense graded Class F type, using MC-3 or MC-4 binder, and the same type of seal coat as used for the road mix. The standard roadway cross-section has been a 3″x20′ oil mat with 5″ edges for both road and plant mix. It is anticipated that future oiled widths on the more important routes will be 22 feet. Standard practice is to use a base course of at least 6-inch compacted thickness unless soil conditions justify a lighter design.

The state has available for use two natural rock asphalt plants, one a commercial plant located near Price in the central portion of the state, and the other a state-owned and operated plant in the Uinta Basin near the town of Vernal. While rock asphalt is usually considered only a high type pavement, the material from these plants has been used in lieu of Class B, C and F on a number of projects near the deposits. The usual design for such work is 1-½″ compacted thickness of rock asphalt on a well compacted and primed base of not less than 8″ thickness. Material from the Price plant has also been used quite extensively as an alternate to bituminous concrete for resurfacing a number of projects in and adjacent to the metropolitan areas. The Uinta Basin plant is located in an area far removed from railway facilities where the cost of manufactured oils is necessarily high. It was opened up for operation by the state a few years ago, with the purpose of securing economy in construction as well as relieving unemployment. This material has been used on a number of projects in the vicinity of the plant and results appear to be entirely satisfactory. The procedure for operating both plants involves blending materials at the plant in order to meet the state's specification requirement of 9 to 11 per cent asphaltic content. The state is now engaged in making some laboratory experiments with the materials from these two plants to determine behavior when mixed with varying percentages of untreated aggregates. Experimental road sections are to be constructed of the combinations appearing most satisfactory from laboratory tests.

As funds become available, it is expected that the state will continue to utilize the road and plant mix types of construction for most of its work where traffic justifies its use instead of the higher type, more expensive bituminous concrete or Portland cement concrete pavement.

Forest and Park Projects

The bituminous work on forest and park roads has been, in general, comparable to the types and methods used by the state. Only a comparatively small mileage of these roads has been so treated. During 1933 a project noteworthy for its type was constructed in Zion National Park. This improvement consisted of a dense graded aggregate plant mix with a rapid curing cutback binder approximating standard grade RC-3. Sealing was accomplished with the same type of oil covered by screenings passing the ⅜″ square screen with 30% passing the No. 10 sieve. The base was primed with light oil approximating grade SC-1A. Reports from the project indicate that the surface has proved entirely satisfactory.

Wyoming

The State of Wyoming started on its way to successful oiled road construction in 1928, although some experimental stretches had been undertaken without success prior to that time. In 1928 the State Highway system was approximately 3,115 miles in length, 40 miles consisting of high type pavement, 1,270 miles of gravel or selected material surfacing, and 630 miles graded and drained, with the remainder of the mileage unimproved. The early construction was undertaken by state forces using road mix methods, an oil approximating our present SC-2, and local aggregates scarified from the gravel surface or added during construction as the case might be. This early work was rapidly followed by contracting both road mix and plant mix jobs in which dense graded aggregates and slow curing oils were used, all construction being of the 2½ to 3-inch oil mat. About this time Wyoming found it desirable to reduce the mat thickness in order to extend the mileage of dustless roads with the funds available. Thin mats of 1 to 1½ inches were therefore constructed on selected projects.

Early in 1935 a survey of the principal portions of the state's system of oiled roads was made and it was found that some 95 per cent of the failures were along the shoulders of the road, only 5 per cent being failures independent of shoulder weakness. Some projects had been constructed by thickening the oil mat at the edge and this was pointed out as having reduced the shoulder breaks. A study in the field was made and it was found that, with few exceptions, the subgrade was constructed flat or without a crown. When the required tonnage of gravel per station was placed and the surface properly crowned the resulting cross-section of gravel base was about two inches thicker in the center than on the edge. It was also found that, where edge thickening had been done, the blade cutting the trench for the edge thickening of the oil mat frequently cut clear through the gravel base into the underlying subgrade. This type of thickened edge construction was resulting simply in substituting oil mix for gravel base and completely ignoring the principal of design in which an adequate base is required under an oiled surface. This field investigation resulted in a complete revision of the design of the state's cross-section for bituminous construction and the present cross-section resulted. First conceding that the edge of the mat is the most vulnerable portion of the surface and subjected to the greatest loads, the state now provides a crowned subgrade in which the crown is 1½ inches greater than the finished crown of the base course. The standard thickness of base course is now 3½ inches at the center and 5 inches at the edge of the mat. Gravel bases are placed for the full width of the road to provide adequate subgrade drainage and avoid impending water at the edge of the oil mat.

In 1935 the state constructed 87 miles of thin oil mat at an approximate cost of $1,650 per mile. This consisted of priming the base with ¼ to ½ gallon per square yard of MC-1, followed by road mixing a windrow of aggregate of approximately 3 square feet end area with either MC-2 or MC-3 and sealing with an RC material. Very gratifying results were secured in this type of work and a considerable mileage is programmed for this year's construction. It was found that better results were secured with MC-3 than with MC-2 and that mixing of the MC-3 was not difficult, so that for this year MC-3 will be used throughout. Projects for this type of construction are selected where traffic is light, good subgrades are encountered, and conditions are, in general, dry. The 87 miles of this type construction in 1935 was inspected in 1936 and its condition was excellent.

The state anticipates that, with regular maintenance, this type will, in general, furnish a very satisfactory service to traffic and, in those places where traffic develops beyond the capacity of this type or other conditions indicate the need of a higher type surface, it will be placed, using this previously constructed thin mat as a base in which the weak spots have been developed and corrected prior to placing of the final wearing course.

Conclusion

From the foregoing discussions covering this vast area of inter-mountain states and covering climatic differences from the constant heat and arid conditions of the Mojave Desert to the heights of the Trail Ridge road in Rocky Mountain National Park where eleven miles lies above timber line and over three miles at an elevation of more than 12,000 feet, it is quite evident that the type of construction undertaken is dependent upon natural conditions encountered only to a small extent. This reminds me of a conversation I had several years ago with one of the officials of the Bureau of Public Roads from the Washington office during a field study of oil roads in this western region. I was asked why the different states employed different types and different methods, and the predominating penetration work of Oregon was mentioned as against the road mix dense graded type of Idaho. I attempted to explain this difference by pointing out the heavy rainfall of Oregon against the semi-arid condition encountered in Idaho. The answer I received after having given what I thought was a very complete and enlightening discussion on the subject was about as follows: "Well, Mr. Ross, your reasons are probably very good reasons, but I never knew before that the lines between different climatic conditions and state boundary lines had been so established as to coincide."

In hot, dry localities the road mix oil mat has proven exceptionally successful. Under these conditions it is difficult to justify the use of a more expensive type. On mountain roads, where detours are not available, temperatures are lower and mountain showers are of frequent occurrence, the plant mix goes a long way toward solving the troubles incident to construction.

The often repeated statement that oiled roads should be placed only on adequate bases is probably accepted by all, but the determination as to what constitutes an adequate base is most difficult. The method of stage construction, wherein the base is given an oil treatment sufficient to carry traffic with reasonable expenditures for maintenance over a period of a year or more, offers possibilities of proving a base and strengthening its weak places which is convincing and easily understandable. Even with this method of stage construction, preliminary investigation and base design should be given the best available in the way of highway engineering. The early belief held by some, that the cheaper the type of surface the cheaper the type of engineering required, has been found wanting.

The successful construction of low cost oil roads requires our best and most intelligent engineering from the selection of materials in our grading work to the maintenance of the finished road.

SUMMARY OF PAPERS ON "DEVELOPMENTS IN DESIGN AND CONSTRUCTION OF LOW-COST BITUMINOUS SURFACES"

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The papers summarized by Professor Lang and Professor Conkling and the subsequent discussions dealt with the subjects of "Analytical Engineering Methods and Research," and "Developments in Fundamentals of Successful Bituminous Practice." Their central purpose was to present the fundamental reasons why certain procedures have been adopted for combining liquid asphalts with various kinds of mineral aggregate, although they necessarily included a good deal of information regarding how the different states are applying these fundamental principles. The function of the group of papers we are considering this morning is essentially reportorial, that is, we are centering our attention on what the different highway engineering organizations have done, are doing, and are likely to do in the next year or two. There is more or less overlap between the subject matter of the previous papers and today's, as it is difficult to present theory without referring to practice, and it is likewise rather unprofitable to present actual practices without discussing the theory back of them.

In summarizing the papers for this section, I have not attempted to present an individual condensation of each paper. The papers have been mimeographed and were given to you a day or two ago, and I assume that you have read all of them. In this section, we found it impracticable to follow the geographical assignments originally contemplated, as they did not provide writers with first-hand knowledge of all of the states, and in the summer time bituminous engineers have little time to obtain and analyze information about states that are strange to them. Also, it appeared that detailed treatment of some of the more important types of work would be desirable.

During the course of preparation of the papers, an attempt was made to obtain quite a large amount of detailed information through the use of questionnaires, reporting costs and details of typical bituminous road jobs done by the different states in the years 1928 to 1932, and in 1936. The information from the questionnaires was tabulated and you each have a copy of the tabulation for the year 1936. It was my idea that a rather interesting presentation of trends might develop from a comparison between the different years.

The comparisons between the data shown for the three years showed quite graphically the trend from the early cheap Class B road mixes of 1928 to the more expensive and carefully constructed plant mix types; they showed also the marked trend from slow curing oils to the cutback asphalts and showed also a marked disposition toward much more substantial base course construction. These trends are also called to our attention in this group of papers. The 1936 tabulation was fairly complete, and appeared to possess enough value to warrant its mimeographing and distribution.

The term "bitutminous surfaces" would, of course, include types of work ranging from dust palliative treatments costing three or four cents a square yard, to asphaltic concrete and heavy penetration macadam costing two or three dollars per square yard, designed for the heaviest traffic and successfully carrying it. Both of these extremes have their economic places, and both have been in widespread use for many years. The subject in which the majority of us present are most interested is, however, the type of bituminous work that lie between these two extremes. Under modern traffic conditions, the cheapest types will not economically serve traffic on our main state highways, and very few of the states are able to finance the construction of any considerable mileage of the high types, even where they are economically justifiable. As a matter of fact, the outstanding bituminous development of the last ten years has been that in which you have all shared; namely, the improvement in design and construction procedure of durable intermediate types, costing 50 cents to $1.25 per square yard for subbase, base and top, and when properly constructed, suitable for traffic up to 1,500 or 2,000 cars per day. Outstanding improvements, of course, have been made in specifications and construction procedure for high type construction, as well as in methods and materials for dustproofing low type roads. However, development of durable low cost bituminous types, and realization of the fact that intermediate types suitable for modern traffic can be built and maintained at low cost on all our very heaviest-traveled roads, has been comparatively recent. Eight or ten years ago I heard doubts expressed that road mixing would provide sufficient improvement over gravel roads to warrant any higher classification than a maintenance operation. In 1936 we find the road mixes and bituminous types comparable in cost, successfully carrying traffic up to 2,000 cars per day, with some engineers maintaining that their traffic capacity is unlimited, if they are properly constructed. California contemplates placing a Class F plant mix on the north approach to the Golden Gate bridge, where traffic of 5,000 cars per day is expected to develop. The question of whether the early enthusiasts for road mixing fine crushed rock or gravel had a really worth-while idea, has thus been definitely answered in the affirmative.

In reviewing the papers, we find that the predominant intermediate bituminous type is still essentially the original dense-graded road mix, classified by the U. S. Bureau of Public Roads as Classes B and C, though the trend is very definitely toward the latter, which utilize cutbacks. This trend is not a development of the past year, by any means; it started several years ago, and our attention was drawn to it by nearly every speaker at last year's conference.

Referring to the tabulation of design data of typical projects, you will note that three states in 1936 used SC-2 or SC-3 in mixes, but provided a sanded or chipped seal with cutback asphalt, and that four states are using SC-4, SC-4a, SC-5 and SC-6, all of which contain a much greater proportion of 80 penetration asphalt than any of the types of slow-curing liquid asphalt previously used. Ten show surfacing types utilizing cutback asphalts or heavy road oil, classified as Grade E asphalt. Mr. Nevitt, at last year's conference, emphasized the superiority of cutback asphalts over SC road oils, on the grounds that supporting power of the mat is a function of the strength of the bituminous cement as well as of the aggregate stability, and went so far as to say that the "general rule may be laid down that road oil hardly pays, even in the construction of the mat, and from a strictly engineering standpoint is entirely unsuitable in any other place in the best type of construction." The above reflects the opinion of a great many engineers, although we still find road oils of the SC-2 and SC-3 grades in successful use in arid regions on roads carrying a high volume of traffic, and we still find that some engineers are using the SC-1a and SC-2 grades for priming, and maintain that they are about as effective as the more expensive MC-1. However, the predominant opinion disclosed by this group of papers is quite in line with the statement quoted above.

In spite of the leading position of the road mixed dense-graded type, the statement made by Mr. Benedict that little improvement has been made in road mix methods in the Northwest is probably true, in the main, of other sections. A number of traveling mixing plants have been on the market for some time, which mix the material on the road or elevate it and put it through a pugmill. However, the purpose of these machines is construction economy rather than to effect any marked improvement in the quality of the work. Ordinarily, machine mixing is just an optional method which the contractor may use with no additional compensation. The time-honored procedure of scarifying existing fine-crushed gravel roads or of adding new mineral aggregate, of spreading this out over the road, giving it three or more "shots" of liquid asphalt with a pressure distributor, followed up by harrowing, blade-mixing and blade laydown, can still be seen any time in the summer in any western state. The improvement in service and performance seems to be due to greater care in the selection of aggregates, the use of heavier grades of liquid asphalt, more skillful workmanship by contractors, closer limitation of moisture content, the almost universal substitution of roller compaction for traffic compaction, and better seal treatments and maintenance than to any basic change in mixing methods. With plant mixes, on the contrary, important improvements in design, specifications, and construction practices are constantly being made. These will be discussed in more detail later.

In addition to the usual crushed aggregate mixes, penetration macadams and surface treatments, which are types which might be designated as "standard," there are a number of other methods which have developed or promise to develop marked usefulness where conditions are suitable. They are not so much distinct types, as illustrations of the adaptability of liquid asphalt procedures to varying local materials, and the resourcefulness of bituminous engineers in utilizing this characteristic. In the

Sierras and Rockies, we find a considerable mileage of road surfaces of roadmixed disintegrated granite. In Nebraska, Mr. Gilmore mentions successful use of local blow sands, which he reported in detail to last year's conference. In Kansas and Minnesota, the old blotter treatment, consisting of two or more applications of liquid asphalt with stone cover on compacted clay mix subgrades proved quite successful and extremely low in cost. Their success is apparently due almost wholly to the fact that the subgrades are well elevated and compacted, drainage is adequately provided, and the clays themselves are non-capillary, or only slightly capillary, and possess very high bearing value as long as water is not permitted to enter from the surface, and a depth of mat sufficient to prevent agitation of the clay surface by wheel action is provided. In Utah, we find that an effort is being made in the Uinta Basin, which is far from any railroad, to utilize a native rock asphalt and to reduce the cost of surfaces built with that material in locations rather far distant from the deposit, by combining it with local crushed stone. Such special types are of more than local interest, as climatic and geologic conditions will vary so much within any one of our large western states that there may be sections in which conditions widespread in Kansas or Minnesota or California may be duplicated and the extremely low-cost methods developed in those states be highly applicable.

In the opening paragraphs of my discussion, I made the statement that western bituminous engineers were interested more in the intermediate types of bituminous work costing from fifty cents to a dollar a square yard, than they were in the extremely low-cost or high-cost types. This general statement is subject to considerable qualification.

A great many of the sparsely populated western states were and are unable immediately to finance even fifty-cents-per-square-yard surfaces for anything like the mileage of roads for which an urgent demand for a dustless surfacing has existed. These states, in order to meet the immediate demands for dustless roads, did a large amount of cheap surface treatment, with the idea of extending the more substantial and durable types of surfacing as fast as their finances permitted. Results on these earlier low types of bituminous work were good, bad and indifferent, depending largely upon more or less uncontrolled local conditions of aggregate, soil, and drainage. No doubt a good deal of money was wasted by state highway departments and by county authorities on some rather conspicuously ill-advised cheap treatments, but I believe the public, on the whole, really got its money's worth. Also, it must be confessed that the men who were advocating and building the more substantial types did not have a 100% record of success. Mr. Roherty points out that untreated gravel roads carrying traffic without failure, sometimes failed seriously when a bituminous surface was applied, even though the new surface added two or three inches to the thickness and supposedly added corresponding strength to the surfacing structure. Also, it was discovered that the roads on which the light bituminous treatments succeeded fairly well, uniformly gave little trouble when a final relatively expensive bituminous surfacing was applied. From these experiences the stage construction method of bituminous work has developed. Technique developed from the cheap treatments were adopted and modified for this purpose. The methods and material used by the various stages differ to some extent, depending upon the character of local material, but the basic idea and procedure is essentially the same in all cases. Descriptions of typical treatments may be found in Mr. Ross's and Mr. Benedict's papers. They usually involve only the application of a half to three-quarters of a gallon of liquid asphalt to the completed surfacing in two applications, with a blotter or cover of material windrowed during reshaping operations, after which the road is turned over to traffic for varying periods of time. Costs from $600 to $1500 per mile are reported. During this period the public has its much-desired dustless road; the maintenance engineer has a chance to discover and correct weak spots in the subgrade, and the construction engineer who later handles the final surfacing can place his relatively expensive top course with some assurance that the base is adequate, even when surface evaporation is cut off, and that his painstaking efforts to get a smooth surface will not be nullified in a year or two by settlements. These preliminary treatments sometimes carry traffic successfully for several years, even though they were originally expected to serve for only a year or, at best, two years. Some of them are excellent illustrations of Mr. Newland's terse statement at last year's conference, that "If the base is what it ought to be, you can get away with murder on the top." The general statement can be made that nearly all of the states employ the stage construction procedure; that the preliminary surfaces usually do serve quite satisfactorily for at least the expected year or two, and that their life can, if necessary, be prolonged by further applications of liquid asphalt. Such annual applications will usually cost considerably more than the annual maintenance charges of the properly constructed durable types, and true economy and public convenience usually demand that the durable type be constructed as soon as the preliminary stage treatment shows the need of extensive re-treatment. Stage construction procedures are mentioned in nearly all of the papers, and increasing resort to this method is quite a marked and significant recent development.

Before getting too far into the matter of bituminous top surfaces, consideration of what the various states are providing for bases is in order. There appear to be two quite definitely dissimilar "schools of thought," in that respect, one holding that we can use relatively light bases and safely depend upon the elastic properties of asphaltic surfaces to adjust themselves to yielding support; the other that no bituminous surface will survive if subject to any appreciable amount of flexing. Referring again to the summary of design data, we find California, Oregon, Washington, Nevada, Utah and Idaho providing total depths of subbase, base and top of twelve to nineteen inches. The total costs vary from $0.64 per square yard to possibly $1.25 (as the subbase costs in Oregon are not included in the 99.3 cents shown). In other states, with the exception of Texas, which shows as a typical project, a one-inch surface treatment on 10 inches of compacted caliche, the total depths run from six to nine inches, though it should be added that Montana frequently employs much greater depths than the nine inches shown, and the project reported is perhaps hardly typical in that respect. The costs vary from $0.45 to $1.25. Assuming that all of the projects shown are adequate in design, one would say that the first group is over designed. However, Mr. Benedict points out that experience has convinced the Oregon and Washington engineers that these heavy courses are necessary if a bituminous surfacing serving traffic adequately with reasonable maintenance charges is to be obtained. Whether maintenance charges on the heavier construction in the Far West are, in fact, enough lower to warrant this heavier initial construction, is of course difficult to decide. It seems to be largely a matter of opinion now, and any defendable conclusion could be reached only after a great deal of study and assembly of maintenance costs and construction data. Possibly the clays in the wild and woolly West are more difficult to tame than those in the central states. At any rate, the very heavy bases function quite successfully, and with a cheap rock supply the costs are not unreasonable.

Mr. Benedict describes in some detail the nature of the materials used for subbase construction in the Northwest. In this connection, the term "subgrade reinforcement" might be a little misleading. We are accustomed to think of reinforcement as structural material of great strength imbedded in weaker material, as reinforcing bars are placed in concrete. Viewed in that light, the term "subgrade reinforcement" would seem to apply more literally to material imported and mixed with the native soil in order to obtain a soil mixture of the desired properties, than to superimposed layers. The subgrade reinforcement indicated on the summary table and discussed in the papers covering the western states is essentially a separate filled and compacted run-of-bank or crushed surfacing, though those states have at times resorted to addition of sand or other materials to correct bad characteristics of subgrade soil, and have also made quite extensive use of thick application from natural earth deposits of the A-1 or A-3 or other satisfactory soil types.

In Missouri and Oklahoma, attention is apparently being centered upon correction or stabilization of the soil itself rather than upon the placing of thick superimposed layers of stone. In many areas in those states, rock is not locally available, and the high cost of building heavy rock subbases and bases practically precludes their use. As a result, Mr. Reagel, Engineer of Materials for the Missouri State Highway Department, has given a great deal of attention to the possibility of stabilizing the native soils with liquid asphalt. He now proposes a design contemplating the mixing of three or four-inch depth of native soil, supplemented where necessary with imported material to correct the grading, with an appropriate grade of liquid asphalt, and upon the surface so stabilized the placing of a light renewable asphaltic surface treatment. The theory back of this design is set forth in his paper presented at last year's Montana Conference, from which I take the liberty to quote:

> "An analysis of the situation brings us to the realization that soil or subgrade support is the basic support with which we have to deal. If at the proper moisture content, the soil will support any practical load, which is true in the majority of cases, then the simple stabilization of the moisture content will achieve our purpose to

> the extent that such stabilization can be made permanent. It is a broad statement, but it follows, that if we can find a practicable durable way to stabilize the moisture content of soils in the field, we will need no other type of construction.
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> "If we are correct in our assumption that a durably waterproof thickness of soil is of just as much value (aside from resisting the abrasion of traffic), as an equivalent thickness of high type surface (again discounting beam strength), we are driven to just one conclusion—get busy on the base and drive in the direction of waterproofed bases plus relatively thin renewable cover costs, as a solution to our low cost road problem. We can get at the thin renewable surface to preserve or improve, but it costs to work on the base after the top has been once placed.
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> "This is the line of reasoning on which we are basing our plan of research attack on the low cost road problem."

It should be pointed out that the Missouri soils work reported in Mr. Reagel's papers of last year and this year comprises three separate developments: First, surface treatments; second, mixes; third, chemical treatment to improve a soil's reaction with bitumen. The first type of work has been done for some time; the second is quite new, and the third is still in the research stage. Dr. Winterkorn's paper on the latter subject will soon be available.

Mr. Reagel's discussion this year on bituminous subgrade treatments is a progress report of the mixing work described in his last year's paper. Both the plant-mixed clay and the "suboiled" silt clay surfaces have passed through a winter, and he now offers some tentative conclusions as to their results. He reports that the suboiled sections on which emulsions were used, came through the winter in such good shape that re-working was not necessary; that the sections on which SC oils were used came through in fair shape, though some sections required re-working, and that the sections using MC cutback asphalt showed rather poor diffusion of the asphalt. The estimated cost of re-working was from $200 to $300 per mile. In view of the low first cost as compared with the high cost of other methods, he believes that the early results warrant further use of that type of work. Oklahoma is also undertaking work of a similar type.

We find no extensive resort to bituminous subgrade stabilization by the Far Western Highway organizations, which can, of course, be explained by the fact that they are pretty well satisfied with the methods of base course construction they are now using. However, lest I give the impression that western bituminous engineers are ignoring this field, I would like to call attention to the fact that District 2 of the Bureau of Public Roads, the California, Oregon and Idaho highway departments have undertaken bituminous subgrade stabilization projects. It should also be added that a large amount of native soil treatment with light SC oils was done many years ago by a number of California counties, and that we have some long-time records of their performance. These are quite completely described in the report entitled, "Light Asphaltic Oil Road Surfaces," by C. L. McKesson, of the California Division of Highways, and W. N. Frickstad, of the Bureau of Public Roads, A variety of types of soil were treated, including sandy gravel soils, sandy loam soils, silt soils and clay soils. The following statement from that report will, I believe, still be subscribed to by most Western engineers:

> "The earliest oil treatment in California consisted of the application of crude asphaltic oil, approximately a gallon per square yard, to the surface of a dirt road. The oil was allowed to penetrate at will, or dirt was thrown on top. This was virtually a surface treatment and generally proved inadequate except for very light traffic or where the subgrade was unusually firm. The next development was the reworking of the thin mat, adding more oil and stirring to a greater depth. This was the crude beginning of the surface mixing treatment. The process was repeated in later years until some of the roads first treated had a surface six inches or more in thickness.
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> "Paralleling the stage development, some of the counties have in the first operation deliberately built an oiled earth surface four to eight inches in thickness.
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> "The success or failure of these oiled natural roads depends largely upon the character of the native material. Sandy, gravelly, or even silty soils have produced serviceable roads in most instances where properly treated and maintained. Heavy clays or alkali soils have been similarly treated, but the results have been almost universally unsatisfactory. These clays are inherently unstable, have

> high moisture carrying capacity, and are constantly changing in volume."

In considering the above statement, it must be kept in mind that the liquid asphalts used were in most cases light, slow-curing oils of the fuel oil variety. In the subgrade stabilization now being undertaken, emulsified asphalt of a special fine aggregate mixing type is employed. The method of application is simple: The material to be stabilized is pulverized to the required depth, dampened and mixed with diluted mixing emulsion applied through a distributor; and is then re-spread, usually in layers an inch or two thick, to facilitate drying out. After the material has been spread and has dried out to a constant moisture content, a light surface treatment is applied. It can be seen that the general theory is quite similar to that stated by Mr. Reagel for his mixed clay surfaces. The amount of emulsion used in the above mentioned western work is about 15% by weight of the No. 200 material. While the method is theoretically applicable to clay soils, containing practically no granular or friction material, economy usually demands the admixture of sufficient granular material to reduce the No. 200 material to about 20%. Even then the treatment is apt to be more costly than eight or ten inches of local run-of-bank material. The treatment has been actively promoted in the West for only two or three years. While not a great amount of state highway work has been undertaken, there have been quite a large number of city, county and airport projects, and the results appear good. Service records are relatively short, but the behavior of the projects under observation is such that it is rather difficult to visualize much, if any, deterioration of the stabilized material through age. A typical road project is that now under way by the California Department between Suisun and Rio Vista. This project is in an irrigated area on a clay subsoil. Eight or ten years ago it received a six-inch course of crushed gravel, the top 2½ inches of which were roadmixed with SC-2 oil. There was a discouragingly large amount of failure. This year an emulsion stabilizing treatment is being applied. The existing oil mixed top and part of the base was scarified and re-mixed with from three to four percent of mixing emulsion. A light asphaltic surface treatment will complete the job. The cost, exclusive of the cost of the seal and the surfacing material in place, is somewhat in excess of $4.000 per mile, of which about $600 was for mixing and $3400 for the mixing emulsion.

In considering the soil treatments, there is an important distinction between the results obtained by mixing slow-curing or cutback liquid asphalt with sandy soils and those obtained by mixing emulsified asphalt with clay. In the former case, the asphalt supplies the binding medium, while in the latter case the clay particles continue to serve as the binding medium, the function of the asphalt being to waterproof the clay. The opinion is frequently expressed that cutback asphalts or slow-curing road oils cannot be dispersed sufficiently to waterproof clay particles, while with the mixing emulsions, such dispersion is actually accomplished. At any rate, on short-time results it can be said that the clay stabilized with emulsified asphalt apparently will not absorb any more water, and remains stable regardless of exposure to moisture.

Mr. Raegel indicates that a further detailed report will shortly be published regarding the progress and the results of the Missouri work. We will await with interest his coming report, and I might add that we will also be very interested in learning of the behavior of these projects after three or four years of service.

In considering the general subject of sub-bases and bases, it appears that the recent development of most importance and widest application is not one of construction procedure so much as one of specifications. We find, in the first place, that less importance is being attached to the hardness qualities of the material used in the lower course, but that greater attention is being paid to the nature of the finer components. As Mr. Reid of Oklahoma points out, this development is largely the result of comparatively recent studies in soil properties and behavior. This is evidenced by the recent appearance in base course surfacing specifications of clauses limiting the liquid limit and plasticity index of the soil portion of the surfacing. Typical specifications along these lines are given in Mr. Reid's paper. Aside from the above restrictions, I do not believe there has been much essential change in crushed stone base course surfacing procedure for many years. With the exception of the Northwest, most states almost invariably use run-of-bank or "crusher run" crushed local material and are utilizing the entire product of the crusher within fairly wide grading limits. There is a tendency to use coarser materials. In order to hasten the compaction and curing of the base courses and thus permit the early application of the preliminary "stage construction" oiling application, resort to compaction by watering and rolling is increasing. The two principal departures from the above general statement occur in the three coast states. In Oregon and Washington, run-of-bank sub-bases and bases are common, but waterbound macadam or modifications thereof are quite widely used for bases. California makes frequent use of the "slurry" base, which is described in Mr. Ross's paper. It involves 2-bin proportioning of the fine and coarse constituents and premixing in a pugmill with water before being placed on the road, where it is carefully shaped and thoroughly rolled. The purpose of the premixing with water and immediate rolling is to obtain an initial uniformity and to prevent later segregation of the loose and fine components which so frequently occur when traffic is depended upon for compaction. It is usually followed immediately by a bituminous treatment, in order to prevent surface ravel. In some cases, the slurry is waterproofed by addition of fine aggregate mixing emulsion during the mixing process.

Regarding the final top course bituminous surfacing, we find that a large proportion of the western states prefer the dense-graded mixes, and that the road mix still leads. The trend toward cutback asphalt and further toward the heavier grades of cutback asphalts and the use of plant mixes is evident. Oregon and Washington are rather notable exceptions, both of them, Oregon in particular, making extensive use of the macadam type of construction. A number of states use heavy asphalt surface treatments of the Armor coat type. Reagel reports Iowa using the Inverted Penetration type, Missouri using surface treatment principally for temporary use, and swinging to the dense-graded mats as a final type on the other roads. Oregon has, in addition, made quite extended use of a modified penetration macadam referred to as "multiple lift," which was developed by Mr. Baldick, and is quite thoroughly described in Mr. Bourne's paper. Bituminous macadams are frequently grouped with the so-called high types and extended discussion of them may appear to be out of place here. However, the cost in Oregon and Washington has not been so much higher than that of many of the dense-graded plant mix types. Referring to the tabulation of costs for 1936, we find Oregon spending 47.3 cents per square yard for 2¾-inch bituminous macadam, and Washington 54.5 cents per square yard for 2½ inches of the same type. We find also that much wider use is being made of the retreads in the Middle West, and the District 3 of the Bureau and the State of New Mexico have also made considerable use of that type. Apparently a great many engineers prefer to eliminate the vexatious matter of quality of fines by simply eliminating the fines themselves. When local fines are bad, their elimination is of course necessary, and in view of the results that can be obtained with the retreads, and the open-graded plant mixes, importation of satisfactory fines does not appear to be warranted. The cost of the open-graded types is not excessive, as the higher cost of the clean crushed aggregate is balanced to some extent by the marked saving in quantities of asphalt. However, Mr. Ross is inclined to question if this type has any essential superiority, in performance, over a properly designed dense-graded type, and indicates that their use is justified only when a definite saving in cost can be obtained.

A closely related type of work is the open-graded plant mix, typified by the Oregon "Cold Mix," described in Mr. Bourne's paper. These have been used largely as resurfacing on old A. C. or P. C. concrete pavement, and in back approach "high type" construction, but with the increasing use of the cutback mixes which cannot be torn up and relaid as could the old S. C. mixes, a need for this type of surfacing will develop as these mixed surfacings develop minor settlements and roughness. Such mixes can be blade spread, and assuming that crushed stone of the desired quality is available at reasonable cost, their cost per sq. yd. inch is not much more than that of the various dense graded mixes. They are suitable for the heaviest traffic, and suggest a further field for our cheaper type: namely, as stage construction on heavy travelled roads, to be followed by a retread, or cold mix resurfacing.

A tendency to substitute plant mix for road mix is noted in several of the papers. The general statement can be made that plant mix is ordinarily more expensive than road mix. Many engineers weighed the theoretical advantages of better mixing, more uniformity in aggregate grading, and less interference with construction by bad weather and traffic, and came to the conclusion that it was worth more. I am inclined to doubt if that conclusion is always justified. Ross cites a Colorado case where the aggregate grading was more uniform in a road mix than in an adjacent plant mix, due to the method of lap-dumping the untreated aggregate for the road mix. In general, if the work is done properly, both types will be satisfactory, and the continued use of the road mixed types indicate that engineers still intend to take advantage of its usual lower first cost. Mr.

Gilmore indicates that constant improvements in road mix equipment are further reducing the cost, and correspondingly slowing up the rate of increase of plant mixing. However, it is evident that the plant mixed surface is undergoing greater changes, and tending to evolve into a definitely higher type than can be obtained by road mix methods. The practical advantages of adaptability to uncertain weather conditions and less interference with traffic are obvious, and they were about the only advantages realized by the first plant-mix specifications, which used the same aggregate specifications and the same liquid asphalts as were used in road mixes. The possibility of mixing heavier asphalts was recognized, but the practicability of utilizing this characteristic to the utmost has been absent until the development of suitable spreading equipment. Nearly all of the papers in this group refer to the use of the self-powered spreading machines, both for the usual plant mixed type, as well as for placing macadam stone.

These machines have been used for some time in the eastern states for spreading asphaltic concrete; however, their application to spreading our low-cost plant mixes has been a comparatively recent development in the West. The action of two typical machines is described in Mr. Benedict's paper and as you have all no doubt seen them in operation, further description now is not necessary. Many engineers question if the use of such machines is theoretically sound with dense mixtures using cutback asphalt, especially of the medium curing types, as no provision is made for evaporation of the solvents. Inasmuch as the solvents are introduced only for the sake of workability and this characteristic is not important if suitable power spreaders are available, the use of hot asphalt without solvent naturally suggests itself. Mr. Ross, Mr. Benedict, and Mr. Gilmore mention the use of this type of work on federal or state projects. No particular construction difficulties are anticipated from elimination of the solvents, and apparently there will be no great difference in cost between such work and the usual Class F mixes utilizing cutback asphalt. On the Pacific coast the 90-95 or 95+ liquid asphalts which approximate a 150-250 penetration Grade E asphalt, are cheaper than the cutback asphalts; probably enough cheaper to balance the cost of the additional heating of aggregate and asphalt necessary at the plant.

Another development in plant mix construction is the substitution of 3-bin or 4-bin proportioning for the 2-bin method heretofore ordinarily used. Mr. Bourne discusses in some detail a Washington project near Coulee City which utilized 4 bins. The cost for a course 22′ wide and 2½″ thick for the plant mix and seal coat was $7500 per mile, or 58c per square yard. Mr. Bourne anticipates some increase in cost from the 4-bin proportioning, but considers that results justify it. District 1 has used 3-bin proportioning on several projects. With the elaborate plants that most contractors now have, provision for the extra bin is probably not an important item, but it is sometimes rather slow work separating on the finer screens. I have not seen any comparative cost data on this point.

You will all appreciate that 4-bin proportioning, the elimination of solvents and machine spreading nearly spells asphaltic concrete. However, the use of our current aggregate specifications, which for the plant mix, do not ordinarily differ much from those for the road mix, and the substitution of our heaviest liquid asphalts or even Grade "D" asphalts without solvent for the cutbacks and the mechanical spreader for the blade-spread, do not introduce much additional cost. If, with careful selection of aggregates and use of the above method, we do obtain something for six or seven thousand dollars per mile, that aproaches the time-tested asphaltic concrete at less than half the cost of the latter, it would be quite a signal accomplishment.

In general, there have been no outstanding developments in aggregate specifications. Most of the states use such tests for hardness as appear practicable, and test all mineral aggregate for reaction with asphalt by using the water-asphalt preferential test or the swell test. I note that Mr. Roherty reports that they have made use of these tests, but have discontinued them because the aggregates in use in that territory always react favorably. There is, however, reason to believe that these two tests are not always sufficient. On a Bureau project this summer, we used aggregate that passed the swell tests, but nevertheless did not hold asphalt when swell test specimens were soaked in water for 24 hours and stirred. We found that much better behavior in this respect was obtained by adding 1% of hydrated lime to the mixture. The recently issued Bureau of Roads Standard specifications require, in addition to the Swell Test, that "The aggregate shall be of such nature that when once thoroughly coated with the bituminous material proposed for the work, the coating will not slough off upon contact with water." We are now working on the problem of standardizing some test procedure to test this quality.

Mr. Roherty very aptly points out that bituminous engineers are still faced with the necessity of adapting their material specifications to permit the use of local aggregate. This, of course, applies to all of our bituminous work, and must be kept in mind if we are to retain the low-cost element which is, after all, of first importance. However, the different improvements and refinements mentioned in these papers, particularly in the plant mixed construction, are of great interest, as any improvement in service that can be rendered by these types of work extends their possibilities and decreases the need for the so-called "high types" which are usually so costly. This extension of the so-called "low cost types" into the field formerly reserved for "high type" construction, is perhaps the most significant development of all.

Nearly all of the states and Bureau offices are using a seal for their bituminous mixes. The desirability of some sort of a seal was recognized quite early in the development of road-mix construction. As a rule, the same oil, usually SC-2, was used, without cover, on the theory that the slight enrichment of the surface both toughened and waterproofed the surface. It was discovered that the leaner mixes showed less tendency to shove, and that it was desirable to favor the lean mixes, but seal the top to prevent surface ravel. Later, most of the states substituted seals of cutback asphalt, hot 95+, or asphaltic emulsions. It was, of course, necessary to cover such applications with a seal coat of stone chips which appreciably increased the cost. At present, a number of the states use the lighter grades of cutback asphalts without cover, and use the heavier RC-3 or -4, hot 95+ or asphaltic emulsions with cover. The trend in the last two or three years has been towards the use of smaller rock for cover. In 1932 or 1933, cover chips as large as ¾-inch were frequently employed. Unless properly keyed, these were often dislodged by traffic and lost, and even if they stuck they produced a disagreeable rumbling effect in most automobiles. At present, few states use seals any coarser than ⅜ inch. The amount of asphalt varies, usually being in the neighborhood of 0.2 gal. per square yard, increasing to as much as 0.3 in areas subject to extremely bad weather conditions. Fifteen to 20 pounds of cover stone is ordinarily required. It might be said that the use of the emulsions and cutbacks as opposed to the hot applications is rather on the increase, as they show less tendency to "bleed" in hot weather. Engineers favoring the heavier applications are somewhat inclined to scoff at the usefulness of the "paint seals" of 0.1 or less gallon per square yard, claiming that they do not prevent the entrance of water and tend to make slippery surfaces. Rock asphalt has also been used to some extent as a seal material.

It is to be noted that the open-graded mixes require a seal of an entirely different type than the dense-graded, as the function is quite dissimilar. The dense-graded types are ordinarily quite resistant to the entrance of water, and the function of the seal coat is to toughen the surface and provide non-skid qualities. The open-graded type is already non-skid, but is apt to be highly permeable unless the voids are closed. On this account, the seal material employed is usually fine sand, which is broomed into "choke" the main course. This is frequently followed by a second seal of cutback or emulsified asphalt, with stone chips.

Although the function of this group of papers is to describe rather than to exhort, I would like to make one plea in closing, namely, that bituminous engineers expand their knowledge of specifications and construction methods in use in other states and thus decrease a natural tendency to depend too much upon only one type of construction. While a single type may suffice for a large proportion of the work, money will be wasted if its use in areas where it is unsuitable or where a cheaper type would be equally suitable, will result. Importation at great cost of fines to replace objectionable fines removed from local materials merely for the purpose of obtaining a typical Class F grading is no economy, though I know of projects where this has been done. Likewise, importation of expensive stone for subgrade reinforcement is not economical if soil conditions are such that a much cheaper bituminous stabilization will be effective.

DISCUSSION ON DEVELOPMENTS IN PRACTICAL DESIGN AND CONSTRUCTION OF BITUMINOUS SURFACES

By N. F. McCoy, Highway Engineer,
U. S. Bureau of Public Roads, San Francisco, Chairman

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Mr. Zaas:
Arkansas

Mr. Chairman, there is one subject that has not as yet been discussed and it may be pertinent. I think it should at least have some explanation, and that is in regard to cotton membrane in bituminous work. I understand that this membrane has been distributed to all of the states for use in connection with bituminous surfacing, and I would like to hear any expression on its use and the desirability of using it.

Mr. Gottlieb:
Alabama

This year we have built approximately 600 miles of surface treatment, in which is included approximately 100 miles that has the cotton fabric membrane.

For our surface treatment work we first prepare our base, which will have a minimum thickness of 6 inches of selected material. After the base has been compacted and is reshaped to line and cross-section, the surface is cleaned with a blower-sweeper unit. Following this the distributor applies approximately 3/10 of a gallon per square yard of tar prime. The prime coat is permitted to dry. Traffic is allowed to travel on the prime as soon as it is dry enough to prevent the wheels of the vehicles from picking up the prime. At times if the prime does not dry in two or three days, or if it is advisable to eliminate the use of the detours sooner, the prime is sanded lightly and traffic permitted on the prime after the sand has been placed.

After the prime is dry we place our surface treatment application. This consists of applying .42 gallon per square yard of 180 penetration asphalt or tar having a float test of 100 at 122° F. This application is applied at one time with a distributor and must be applied within 5% of the above amount. As soon as the bitumen is applied it is covered with .55 cubic foot per square yard of aggregate. The aggregate is stone, slag or gravel and when tested with square mesh sieves will have 95% to 100% passing the 1-inch and not more than 10% passing the ½-inch sieve.

The aggregate is spread by spreader boxes attached to the truck. After the aggregate is spread it is broomed lightly and rolled. Traffic is permitted on the road as soon as the aggregate is spread. Usually it requires about twenty minutes to shoot and cover each distributor load, and traffic is held up during that time.

When the cotton membrane is used the construction method is changed slightly. The cotton is delivered in wide rolls—82 inches wide. It takes three rolls to cover the width of our 20-foot pavement. Before the cotton is used, we place a string line on each side of our 20-foot pavement. Then we start three men rolling out the cotton membrane on each side, using the string line as a guide to keep the edge of the cotton at the edge of the pavement. Following the crew on each side is a crew rolling out the center roll of cotton. The cotton is tacked only on the outside edges of the road. By doing this, it prevents the cotton from shrinking on the edges, as that is where you want the best support. We have tried two methods of placing the cotton. The first is to prime the surface using about .05 to .1 of a gallon per square yard more tar than would ordinarily be used and then roll the cotton on the wet tar prime. In this method all traffic must be kept off the road from the time the prime is placed until the surface treatment is finished, for the reason that the wheels will pick up the cotton and either mess it up or roll it up on the wheels of the car. After the tar has dried we place our surface treatment application as explained above, except that we have to increase the bitumen in the hot application between .05 and .1 of a gallon per square yard, depending on the grade of cotton. The other method is to prime the surface as we do in our ordinary work and allow traffic to use the prime road until we are ready to finish the work. Then just before the hot application of bitumen is placed, we roll out the cotton and shoot the bitumen on top of the dry cotton. The amount of hot bitumen used in this method is about the same as used in the first method, which was previously described.

Our present investigation of the completed work indicates that the cotton membrane has a tendency to retain the hot bitumen and in so doing will give longer life to the pavement because it will keep sufficient asphalt close to the aggregate making a waterproof surface, and also give a pavement that is not too fat, as the extra bitumen is being held by the cotton. We have also noted that there is more flexibility to the pavement when the cotton membrane is used. The cotton reinforcement is particularly good for the edges because it strengthens them and thereby will prevent so much edge failures, which we have had due to lack of edge compaction, wagon traffic, and from other things caused by the difficulties encountered in construction.

We have tried all three grades of cotton; however, I am not familiar with the details off hand of the size opening and weight of the three grades. At the present time we believe that the closely woven grade called grade A gives the best results because it will have a tendency to hold more of the "reserve asphalt" than the other more open grades.

Mr. Stackhouse
Washington

What is the application of asphalt that you put on the edges?

Mr. Gottlieb:
Alabama

Our surface treatment is similar to your Armor-Coat and in our state is made by applying .42 gallon per square yard of bitumen. The entire amount is applied in one shot. This is covered with aggregate.

Mr. Stackhouse
Washington

You mentioned that you tacked down the edges of the cotton mat. What did you use as tacks?

Mr. Gottlieb:
Alabama

We use wire staples about 1 inch long. They are placed at 3-foot intervals. The staples are long enough so that they hold if the cotton shrinks. The staples are used because the cotton will shrink sometimes due to the saturation of bitumen; or water from rains. The cotton will shrink 3 or 4 inches and if not stapled, the shrinkage might be at the edge of the roadway where the best support is needed.

Mr. Benedict:
B. P. R.

I should like to make it clear as to the openings in the cotton membrane. Mr. Gottlieb spoke of densely woven material. The strands are actually about ⅛″ apart, giving the appearance of cotton string woven into the form of a fish net. The asphalt goes through the openings and serves to tack the material to the base course.

Mr. Houk:
Alabama

I might say in this connection that we have under consideration a modification of the use of this where it is very desirable to reinforce the edges. That is, to use two strips—one on each edge, each 36″ in width. Lap half over the edge line of the pavement, apply the hot asphalt or tar and fold it back, giving a double thickness at the edges. There is no need for the cotton under the surfacing in the middle of the road. Where you do have a type of thin asphalt mat which is subject to edge failure, this should prove of material benefit.

Mr. Schwegler:
B. P. R.

During the discussion yesterday some one recommended a rich mixture, that is a high asphaltic content. The general practice in the western states, I believe is entirely opposite. It has been found that the best results are secured by using drier mixes, and using a seal coat to waterproof the surface and give a tougher wearing surface. A large part of the failures in the West, in the oil mats themselves, have been due to use of excessive oil in the original mixture.

Mr. Muir: Utah

I think maybe that came out in the paper I presented. The Utah formula for oil content provides for less oil than those used in New Mexico or California. Our practice has been to take a little oil out of the mixture and use it for sealing. We use a heavy cutback seal with stone chips. The richest mixture that will still retain sufficient stability is the one that will be most durable.

Mr. McCoy: B. P. R.

Any further questions?

Mr. Barnes: Kansas

I would like to take this opportunity to clear up any misunderstanding that might arise relative to the summary of low cost roads for 1936 as regards Kansas. You will note that in the summary we show under base course a cost of 97 cents per square yard, which for the particular project that we report is correct, but the thing the summary does not bring out—and which I would like to bring out—is the fact that the base course was only used on a small portion of the project. The total cost on that project you will see from the last column shows $1.248. That is not the fact in the case because the total cost per square yard on the project was somewhere between 50 cents and 60 cents per square yard. What they have done here is to add the cost per square yard of the top course, plus the cost of the base course which is not the correct figure to use, because the base course was only used in sections of 300 or 400 feet through bad hill cuts, etc. Just wanted to bring that out because our cost per yard of bituminous mat roads runs anywhere from 35 cents to 65 cents per square yard.

Mr. McCoy: B. P. R.

I think you had the matter clear in the data which was given to me. I realize that on the project itself there were a good many sections that would not need additional strength. However, the summary shows the cost of the type of work described in the design data.

Mr. Benedict:
B. P. R.

The thoughts of this group seem to lie almost entirely along the lines of bituminous road and plant mixtures, etc. I should like to ask Mr. Houk of Alabama to tell us about the work they have been doing in armor coat construction.

Mr. Houk:
Alabama

We have a very large mileage of graded roads that have been surfaced during the past with sand clay, clay gravel, top soil, crushed stone and other types of granular and earth types of temporary surfacing. In connection with the Works Progress Administration and the counties last year, we embarked upon a program of surfacing these roads. Our experience in the past has been the same as other states. We have gone into the study of base and foundation courses and found that the materials which were suitable for unsurfaced roads were unsatisfactory for base use because they contained too high percentages of clay or binder. So on these surfaced roads where the surface had worn away, washed away and blown away until there appeared to be maybe 3″ or 4″ remaining (it actually varied from ½″ to 4″ or 5″ in thickness), we built up these base or foundation courses after careful investigation of the local material, utilizing the local material within economic hauling distances. We built these bases up to a minimum of 6″ or 8″, depending upon the type of base course material and after they were compacted we surfaced them with "armor coat" or inverted penetration.

The theory of design of this treatment is somewhat similar to that of a bituminous roof. We first prime the base course, after it is compacted, finished, and smoothed, with a tar prime. We find it superior to an asphalt prime. We use the tars produced in our state and naturally we are inclined to use those materials produced within our state.

In states where there is a large amount of rainfall, tar is believed to be superior because it is more resistant to water than asphalt.

Mr. Houk: Alabama

We place a prime coat of about .3 to .4 of a gallon per square yard. After this prime coat has dried out for three or four days or longer, we apply a hot coat of 180 to 200 penetration asphalt at the rate of around .38 to .45 gallons per square yard. Immediately following this we apply the coarse aggregate layer. We endeavor to obtain as nearly one size aggregate as practicable. We endeavor to obtain a thickness of mat coat from ¾ to ⅞ inches. An ideal grading would be ¾ inch uniform cubes. However, to be within practical limits our material passes a 1″ or 1¼″ and all but five to 10% is retained on the ½″ screen. This is applied immediately on the hot asphalt immediately behind the distributor, by hand or mechanical spreaders. We distribute one load before the next load of asphalt or tar is applied. This gives us a uniform layer of aggregate the thickness of the aggregate over the width of the treatment. The road is then opened to controlled traffic after rolling. We use traffic dividers in the center in order to distribute traffic over the full area. After a week or ten days' traffic the stone becomes firmly imbedded in the bitumen and mechanically interlocked. This makes a fairly good riding surface and could be left for a year for light traffic. However, we cover the mat with a seal coat within from 30 days to six months, either of premixed material or drag seal application. In the pre-mix treatment, we mix the material in one of these small mixers that have been recently developed. The Jaeger Kwick-Mix and Blystone are examples of the type, and it is surprising the amount of material that one of these small mixers will turn out. Recently we have had several setups where we were able to turn out 200 tons a day with one 12-cubic-foot mixer. We find it takes 25 to 30 pounds of pre-mixed material passing a ⅜″ mesh to make a satisfactory seal coat.

The other method is drag seal. We use about .2 gallons of cutback either the RC-1A or RC-2.

On top of this, we immediately spread 18 to 20 pounds of slag or stone chips passing a ⅜″ mesh and retained on a 10 mesh sieve. Following that we shoot the .2 to .23 gallons of cutback on top of the chips and then follow with a drag broom. It really constitutes a road mix seal.

We believe that this "armor coat" or double bituminous surface treatment is superior to any type of road mix for our section. Our section has a great deal of rainfall and it requires a bituminous surface that is very resistant to moisture. Really what we have corresponds to a bituminous roof on a building. Our base or foundation course carries the load.

In my observation of some 32 states, I find that practically every failure in bituminous and concrete pavement can be attributed to defective sub-grade or base or foundation course. I think failures in the base constitute one of the most serious problems that we have to deal with. We have spent too much time on the theoretical design of the pavement and too little on the foundation that carries that pavement or surfacing. I believe further that our research should be directed to the study of the pavements and wearing surfaces that have already been built and are in service. I think in this study we can find what not to do and in the course of time we find what we must do to build dependable and durable pavements in each locality. In the road tests made in the past all of the factors involved have not been taken into consideration. Over-stress has been laid on the effects of traffic which often only is a minor factor in the design of the road. I think the greatest factor is nature and her disintegrating and destructive processes. I do not think that any one section can tell another section how to solve their problems. The best we can obtain from other sections is an approach to the solution of our problems.

My approach to the solution is that I think we as highway engineers must give more time and effort to the utilization of materials which we have in our own sections. Each road is a particular problem just the same as a bridge is a particular problem.

We are glad to have had the opportunity of being out here and have certainly enjoyed our trip out here and our visit with you. We have no criticisms to offer. We think you have some of the finest roads that we have traveled over, and we think this is the greatest conference that we have ever attended.

Mr. Kirby: Utah

I have been wanting to know a simple thing and that is if there is any correlation between road temperature before seal coat is applied and your finished quality of the road. Quality is not exactly the word I want to use. I had an occasion not long ago to check a road that was finished except for seal coat. I started at a point where the seal coat had been put on at 8 o'clock in the morning and I followed it through during the day. In the early morning where the seal was applied to a cool surface, the road looked fine. But at a point where the asphalt was applied around noon the stone chips had been kicked off and the road surface did not look very well. In the afternoon it looked better and toward evening it looked good. I took a thermometer and buried it in the road to see what the surface temperature was and I got temperatures as high as 140° F. At that temperature the MC's and RC's, in my opinion, penetrate too rapidly. When chips are applied there is nothing to hang on to, the seal coat has gone on down. I am wondering if this observation is correct and if someone else has observed the same thing.

Mr. Powers: Arizona

In connection with the comments made by Mr. Kirby, in Arizona from time to time, and particularly in the summer time, that particular condition arises and we have to seal coat at night. We make the contractors work at night, or early in the morning, say start at 4 and work until 9 that same morning and then lay off until the next morning. This condition exists particularly with the cutback asphalts where cutbacks are used as a seal on mats having a fairly open texture.

Mr. Muir: Utah — We have been having much trouble in obtaining a satisfactory seal on our oiled surfaces, when the work is done soon after the material is placed under traffic. Much of the cutback is absorbed in the mixture. At such places on the surface the cover material fails to stick. The resulting surface is very streaked. To overcome this condition we have given the surface a preliminary application of either SC road oil or cutback. This treatment plugs up the surface so that the later application of RC cutback all remains on the surface and the cover material is held in place and the resulting surface is very even in appearance.

Mr. Saville: Missouri — So far the Conference Board has had no question and I should like to present this thought for discussion. What is the reason for using, or for not using, a prime? Why do some use it and why is it that some do not use it? I should like to hear a discussion of this subject.

Mr. McCoy: I will ask for volunteers.

Mr. Gottlieb: Alabama — In our surface treatment work we believe the prime coat is essential for several reasons. It acts as a dust layer and helps bind the particles of sand on the surface. As the prime penetrates into the base, it helps stabilize that part of the base and therefore adds to the structural part of the pavement. After placing the prime coat and allowing traffic to use the road, it further compacts the semi-loose material that might be on the surface. The prime also acts as a better binder for the next bituminous application. Bituminous material will adhere much better to a primed base than one which is not primed. Construction work can be carried on better and quicker when working on a primed base because there will not be any delays in waiting for the base to be shaped or reshaped, and after rains the primed surface will dry and be in shape to resume paving much quicker than when the base has not been primed.

Mr. McCoy: Does that answer your question? I might say that in the far Western states a prime coat is almost universally used for the reasons just given, and because of the fact that they can have a good road to operate on during construction, and the road is not likely to be so susceptible to damage by trucks.

Mr. Houk:
Alabama

I might say that we feel we obtain added mat thickness where we have a good granular base course material because as the prime goes down ⅜″ to ¾″ that much thickness is added to the bituminous thickness.

Mr. Draper:
Mississippi

The method outlined by Mr. Houck has been used in Mississippi. On one project late last year when the temperature got down to about 50 degrees the 150-200 penetration asphalt cooled so rapidly that the crushed gravel chips would not stick. In order to finish the project that season we tried an experiment and had the refinery add about 8% of naphtha to the asphaltic cement and we had no difficulty whatever and even after four or five hours the wet, cold chips would successfully stick That is one way of lengthening your construction season if you are interested in that method.

Mr. McCoy: There is a question I should like to ask which has not been brought out yet, which is an interesting one. That is, what type of asphaltic type surface will stand the wear and tear of heavy snow removal equipment? Some cheap types do stand it; but some engineers state that even the best asphaltic types do not stand it. The question of proper design for this purpose is important.

Mr. Ross:
B. P. R.

We have had no trouble.

Mr. McCoy:

Will you describe your experience?

Mr. Ross:
B. P. R.

On our mountain pass work, where we handle snow removal all winter, it has been the practice to leave a layer of snow over the oil mat and hold the equipment up on that. We have not yet had a great amount of trouble with tearing up the oil mat. Maintenance men watch that, and since they are responsible for all repair work they are very careful to keep their equipment from tearing up the mat and we really encounter very little difficulty.

Mr. Donohue:
Montana

In snow removal work, it has been our practice to try to get out with the storm and clear our roads completely of snow and in our 3,500 miles of bituminous roads we have not had any failures that I can recall due to the action of the snow removal equipment on the mats, that is even on the thin mats.

We are now getting into a proposition which should make a good discussion—that is the relative thickness of bituminous mats. I don't know whether that should be discussed as a construction problem or as a maintenance problem this afternoon. But getting back to the question of snow removal equipment, we have had no trouble, even on the thinner SC mats. We have not tried in any way to develop an oil mat that would not be affected by snow removal equipment, but we have always attempted to get the snow off the roadway as fast as possible to prevent its melting there and running over the roadway and under the mat edges.

Mr. McCoy:

You have comparatively light snow in Montana; that is, compared to the passes in the State of Washington or in the Sierras where the snow is too heavy to remove with a blade. The snow becomes 30 or 40 feet deep. We have had one or two rather tragic experiences on some of our Bureau work, where the mat has been torn up pretty badly.

The problem is to provide a surface that will stand up under heavy equipment like the Sno-Go.

As our time is up, that will conclude the meeting for this morning.

SECTION IV.

PAPERS PREPARED ON MAINTENANCE OF BITUMINOUS SURFACES AND ANALYSIS AND REVIEW OF THESE PAPERS AS PRESENTED AT THE CONFERENCE BY THE CHAIRMAN OF THIS SECTION.

MAINTENANCE OF BITUMINOUS SURFACES ON STATE HIGHWAYS IN NEBRASKA AND KANSAS

**By C. M. Duff, Professor of Engineering, University of Nebraska,
Testing Engineer, Department of Roads and Irrigation**

In preparing this paper the outline submitted by Mr. H. G. Nevitt, who will summarize the various group papers on maintenance of bituminous surfaces, has been followed as closely as possible.

On account of the large field covered by the outline it has not been possible to supply the requested information for all items listed. Due to a misunderstanding, no request was made to Kansas for information until the first of August, which did not permit sufficient time for them to supply as complete and detailed information as their experience with bituminous surfaces justifies, and it is unfortunate that this paper does not more fully cover the details of maintenance in Kansas.

In the discussion which follows, the information given under the various headings for the two states is given first for Nebraska and then for Kansas.

Maintenance Organizations

The maintenance organization of Nebraska is supervised by a maintenance engineer who is directly responsible to the state engineer. The state is divided into eight districts, each of which is composed of about ten or twelve counties. Each district is in charge of a district engineer who supervises both construction and maintenance and who is responsible to the maintenance engineer for the maintenance activities in his respective district.

The highways in each district which are eligible for state maintenance are divided into patrol sections which vary in length depending upon the type of surfacing, traffic, topography, and soil. Where a nearly continuous length of bituminous surface has been constructed these patrol sections may cover as much as fifty miles in length, but where isolated projects of bituminous surfacing have been constructed each project may constitute a patrol section. Each district engineer generally has about six chief patrolmen under his supervision who are in direct charge of the maintenance for a group of assigned patrol sections.

The maintenance organization for Kansas consists of a maintenance engineer who is directly responsible to the state engineer and director. The state is divided into six sections and each of these is subdivided into four or five districts. Each division is in charge of a division engineer who supervises both construction and maintenance. Each division engineer is assisted by a district supervisor for each of his districts, who is in direct charge of the maintenance operations. The highways in each district are divided into route sections, the limits of which are established by county lines and intersecting highways.

Organization and Equipment for Routine Maintenance of Bituminous Surfaces

In Nebraska the routine maintenance of bituminous surfaces is performed by a crew of from two to five men, depending upon the length of the patrol and the season of the year. Each crew is equipped with a truck, roller, asphalt kettle, and all tools necessary for repairing surface and shoulder failures. Small quantities of asphaltic oil are stored in barrels at each of the patrol sheds. Patching material is available either from stock piles placed at intervals along the road or from the patrol sheds.

In Kansas the routine maintenance of bituminous surfaces is taken care of by a section man and a helper, who maintains a route section approximately thirty miles in length. They are equipped with a 1½-ton truck, light blade, small tools, roller, mower, snow fence, and snow removal equipment. Patching material and small storage space for oil are provided. The daily maintenance duties of the section man consists of patching small faults, rolling shoulders, cleaning right-of-ways, ditching, shouldering, and resetting guide posts, guard rail posts, and road signs.

Organization and Equipment for Special Maintenance of Bituminous Surfaces

In Nebraska special maintenance of bituminous surfaces is performed by crews assembled from the district in which the work is to be performed. The equipment used is also assembled from the district in which the work is done except that in a few districts a distributor is sent out from another district or from the Lincoln supply base.

The major equipment used in special maintenance work, which is not definitely assigned to a particular district but is available to be sent out when and where needed, is composed of two distributor trucks, four trailer distributors with two tank trucks each, four aggregate spreaders, several windrow gauges, and a tank car heater for each distributor unit. All other major equipment used, such as motor graders, "cats" and blades, is assembled from the district in which the work is done.

In Kansas each division has a trained oil crew to take care of special maintenance of bituminous surfaces. These crews work over the whole division in which they are located. Each crew is supplied with an 800-gallon distributor, necessary blade equipment, from one to five 1½-ton trucks, and other necessary equipment for sealing long sections, scarifying and reconditioning mats, oiling shoulders, and making base repairs. They are equipped to completely build any type of bituminous surface if necessary. Kansas also maintains district oil crews, which are essentially the same as the division oil crews with the exception of equipment. They have a two-wheeled trailer-distributor of 300-gallon capacity, a 1½-ton truck, and small tools. Patching material is available at the section man's shed. The duties of the district oil crew are to take care of minor repair jobs such as spot sealing, patching, and repairing short sections. When the surface is in such condition that routine maintenance is all that is necessary the district oil crew is free for any other necessary maintenance duties.

Organization Policies Covering Major Maintenance Repairs of Bituminous Surfaces

In Nebraska, on bituminous surfacing projects where major maintenance work is involved, the maintenance engineer inspects the project with the district engineer and a decision is made as to the length of surfacing requiring major work. The district engineer then prepares estimates of material required and a summary of the proposed method or methods of repair and submits this information to the maintenance engineer for approval.

On many of such projects the maintenance engineer requests the Division of Tests to make a study of the failure or failures on the project, determine the cause, and propose a remedy. An engineer from the Division of Tests then makes a detailed inspection of the project, designates points where samples should be taken, and makes notes on the types of failures.

The Division of Tests classifies the failures as to surfacing or base failures and, after the samples are analyzed, prepares a detailed recommendation sheet with one or more methods of treatment which lists the materials and proportions required for making the proposed repairs. This information is submitted to the maintenance engineer, who makes the decision as to the method and extent of the major repairs.

Major repair work is generally supervised by the chief patrolman or resident engineer, but when a considerable amount of work is necessary or when specialized work is involved, a project engineer, who is specially trained and has had considerable experience, is designated to take charge of such work.

All materials used in maintenance repair work other than routine are submitted to the Testing Division for test and approval.

Information is not available from Kansas as to who designates the sections which are to receive major repair work or who assumes the responsibility for analysis of failures and makes the decision as to the remedy. They report that under their well organized plan of maintenance the department has developed a number of very efficient employees who understand the proper methods to use in correcting and improving their bituminous types of highways.

Mileage of Bituminous Surfaces

The total mileage of bituminous surfaced roads under maintenance in Nebraska as of January, 1936, was 638 miles, which was composed of 449 miles of bituminous mat and 189 miles of bituminous sand. New construction in 1936 will increase the mileage of bituminous mat by approximately 143 miles and the bituminous sand by approximately 70 miles, and will add 17 miles of surface-treated stabilized base, a type of bituminous surface which is being used for the first time this year. This will place approximately 868 miles of bituminous surfaced roads under maintenance by the end of 1936.

Kansas reports the total mileage of bituminous surfaced roads under maintenance as of May, 1936, to be 2,848 miles, which was composed of 1,772 miles of bituminous mat, 35 miles of oiled earth and 1,041 miles of oil penetration. New construction in Kansas includes 118 miles of course aggregate type bituminous mat, 299 miles of dense graded type bituminous mat, and 115 miles of oil penetration. Some of the new construction mats will be laid on existing bituminous surfaces.

All mileage of bituminous surfacing in both Nebraska and Kansas is given routine maintenance. Kansas reports that approximately two-thirds of their mileage has been given special maintenance and this figure also applies to Nebraska. Table 1 shows by years the number of miles and the kind of bituminous surfaces constructed in Nebraska and the approximate mileage given special maintenance. This table groups the surfacing under the two headings, Bituminous Mat Surfaces and Bituminous Sand Surfaces. The table also shows the type of special maintenance given, cause of failures, and whether the work was done with construction or maintenance funds.

Kansas reports that their special maintenance consists of: "true seal coating" 75 miles, "armor coating" 1,500 miles, and reworking or reconstructing 300 miles.

Traffic Statistics

The correlation of traffic statistics and maintenance costs is a debatable question and a problem that is difficult to solve. In studying the relation of maintenance cost to traffic count several factors must be taken into consideration. Due to the many types of bituminous surfaces that are constructed, it would first be necessary in making a comparison of traffic count and maintenance cost to limit the comparison to some one type of surfacing. The maintenance on a cheaply constructed surface should not be compared with a better constructed surface having the same traffic count. In the second place, it is necessary to differentiate between the number of vehicles using a road and the class of traffic or traffic load the surface must support. And in the third place, it is necessary to take into consideration climatic variations such as prolonged periods of high temperature or wet weather.

On several bituminous sand roads in Nebraska considerable damage has been done by heavily loaded trucks operating during prolonged periods of hot weather. These same trucks could pass over the same road thousands of times during periods of normal temperature without causing appreciable damage. The same is true for bituminous mats whose subgrade material, due to low grade or to insufficient drainage, has become softened by prolonged wet weather.

No doubt there is some relation between maintenance cost and traffic count, but in Nebraska it is not definite or fixed and maintenance cost does not necessarily increase with traffic count. Maintenance cost may be expected to increase with the traffic count on poorly constructed or light traffic surfaces, but if a surfacing is inadequate for the maximum traffic load to which it may be subjected the maintenance cost will probably increase in a much greater ratio than the traffic count. On the other hand, if the surface and subgrade are adequate for the most severe type of traffic load, the cost of maintenance should not be materially different for either a high or low traffic count.

The above statements are not in agreement with information supplied by Kansas, as they maintain that for Kansas the surface maintenance expenditures on a surface exclusive of replacement of materials is in direct proportion to the volume of traffic. The values shown in Tables 8 and 9 for maintenance cost of bituminous surfaces in Kansas do not appear to bear out their statement. However, there may be some further explanation which is not self-evident from these tables.

When properly analyzed and applied, a traffic count should materially assist in selecting an economical type of surface, but it does not predict accurately what may be required of the highway after it is improved. In the past Nebraska has not had a complete traffic count, but at the present time an extensive traffic survey is being conducted by the Department of Roads and Irrigation, in cooperation with the U. S. Bureau of Public Roads, as one phase of the highway planning survey. The traffic counts shown in the following tables of surface maintenance costs were compiled from incomplete data obtained during the past four months.

In Kansas a complete survey of the traffic flow on Kansas highways was started in 1933 by the Maintenance Department. This work was conducted with the regular maintenance forces with no additional expense to the Highway Department as a

C.W.A. project was approved for the tabulation and clerical work connected with the survey. Their survey shows hourly totals for both automobiles and trucks and these are separated into the number of Kansas vehicles and the number of foreign vehicles. A further division is made to show the number of trucks having a capacity of less than one ton and over one ton.

Methods of Cost Keeping

For Nebraska the methods used in cost keeping for bituminous roads are in general the same as for other types of roads. All maintenance is divided into the following classes: Class 1, surface maintenance; Class 2, roadway maintenance; Class 3, equipment maintenance; Class 4, office administration; Class 5, miscellaneous; Class 6, supply base maintenance; Class 9, markers and sign refinishing and stocking department.

Each of these classes is subdivided into a number of separate items pertaining to the class of work done. Under Class 1, surface maintenance, appears the following items for surface maintenance on bituminous roads:

Item 6—Bituminous Mat or Oiled Sand Road Repairs. This item only covers routine repairs. It includes the patching of holes, the repairing of small surface breaks and raveled shoulders, and the dragging or blading of the oiled surface if such is required.

Item 16—Construction of New Oiled Surfaces. This item includes the first seal coat if placed within ninety days after the mat is completed or if placed in conjunction with the construction of the mat, but it does not include the preparation of the grade.

Item 19—Preparation of Grade Preparatory to Oil Construction.

Item 20—Bituminous Mat or Oiled Sand Major Repairs. This item includes the reconstruction of the surface, and covers the operations of tearing up, remixing and laying down. It also includes the addition of any new bituminous products or aggregates (including fillers) that may be required.

Item 21—Seal Coating Oil Roads, Including Cover Material When Applied in Conjunction With Sealing. This item does not include minor sealing of small areas or patches, as this work is included in Class 1, Item 6, and it does not cover a first seal coat placed within ninety days after the mat is completed, as this work is covered by Class 1, Item 16.

Maintenance costs are also listed by commodities in addition to being classified by class and item.

The following paragraphs on methods of cost keeping for Kansas are taken from the Ninth Biennial Report of the Kansas State Highway Commission dated June 30, 1934, page 217:

"Cost accounts for the maintenance of Kansas highways have been divided into two groups, which carry information under several related headings. All costs are given according to the type of road surface and on one report is shown the mileage of each type, and the maintenance cost of surface, roadbed, structures, snow removal, detours and total expenditures. This also tabulates the cost per mile of maintenance and miscellaneous construction, and the cost of resurfacing in total and per mile.

The second group classifies the same total expenditure according to regular salaries, extra labor, equipment rentals, material, right-of-way, payments to counties and cities, payments to contractors and miscellaneous items."

No detailed outline for the separation of the maintenance costs on bituminous surfaces by items was made available for Kansas.

Comparative Maintenance Costs for Bituminous Surfaces

Tables 2 to 10 inclusive show construction and maintenance costs for bituminous surfacing projects in Nebraska. Data for all bituminous surfacing projects can not be shown as some patrol records include several types of surfacing. Of the total 419 miles under maintenance in 1934 these tables cover the maintenance costs for a total of 376 miles.

The surface maintenance costs shown in these tables include all maintenance of the surface except equipment maintenance and depreciation, administration, and miscellaneous expenses.

The items not included are chargeable both to surface maintenance and roadway maintenance. The last column of the tables gives the average total maintenance cost per mile per year as shown by the auditor's statement and includes these items as well as all items of every kind representing a maintenance expenditure on the patrol.

The number of years shown under the column headed "Number of Years Maintenance Cost Recorded" dates from the time the Maintenance Department assigns a new patrol number or makes separate maintenance charges on the new construction. In many cases several months may elapse after completion of the construction work before maintenance charges are started.

The column headed "Condition of Surface" is only intended to show the relative rating as compared with other bituminous surfaces throughout the state. This rating would vary with the individual making the inspection and also with the time of the year that the inspection was made. Some of the projects listed as being in fair to poor condition and having poor riding surfaces may be almost as good as the best in some other state.

The costs shown for surface maintenance does not always give a true picture of the amount of work that may have been required on a patrol. Very little surface maintenance has been required on the major portion of several patrols that show fairly high surface maintenance costs due to the expense incurred in repairing a comparatively short section which had been built on a base that was unsatisfactory at the time the mat was constructed.

The following are a few approximate average costs exclusive of engineering or administration for typical maintenance operations in Nebraska: (1) A cost of $0.01 per square yard per 0.1 gallon applied for sealing with MC or RC asphaltic oil and covering with sand or gravel from the roadside. (2) A cost of $0.012 per square yard per 0.1 gallon applied for sealing with MC or RC asphaltic oil and covering with shipped-in cover material. (3) A cost of $50 per mile for scarifying and reshaping half of the depth of bituminous sand surfaces constructed with SC asphaltic oil. (4) A cost of $200 per mile for scarifying, remixing and reshaping the full depth of bituminous sand surfaces constructed with SC asphaltic oil. (5) A cost of $600 per mile per inch of depth for reconstructing bituminous sand surfaces 21 feet in width including the addition of filler and MC-2 asphaltic oil. (6) A cost of $400 per mile per inch of depth for reconstructing bituminous sand surfaces 21 feet in width including the addition of RC-2 asphaltic oil but without the addition of filler. (7) A cost of from $200 to $250 per mile for tearing up and relaying bituminous mats constructed with SC asphaltic oil which do not require the addition of aggregate or asphaltic oil.

Table 11 shows a summary of maintenance costs in Nebraska and Kansas for various types of bituminous surfaces.

Tables 12, 13 and 14 show typical data for the three types of bituminous surfaces constructed in Kansas. All sections are complete maintenance sections and in each section there is only one type of surface. The sections were taken indiscriminately from all parts of the state and no attention was paid to type of aggregates, oil or physical characteristics of the grade on which the surface was laid. The costs given under the column headed "Routine Maintenance Per Mile Per Year" include surface maintenance, shoulder treatment, drainage, roadside improvements, snow removal, guide line painting, detours, and all work on highway route markers, but does not include resurfacing.

Since the same maintenance items have not been used in compiling the tables showing cost of maintenance in Nebraska and Kansas, no direct comparison can be made. The last column of Tables 12, 13 and 14, showing cost of resurfacing plus routine maintenance per mile per year for maintenance costs of Kansas highways should be directly comparable to the last column of Tables 2 to 8, inclusive, showing total maintenance cost per mile per year for maintenance costs of Nebraska highways, and to Tables 9 and 10 by adding to the figures shown in the last column the cost of sealing paid from construction funds which are shown in the column under special maintenance sealing and have the exponential letter "a" after the figure. However, the above comparison is not a true comparison as the Kansas tables do not show the age of the surfacing or the number of years that it has been under maintenance. The resurfacing charges in the Kansas tables may appear much higher than the sealing charges shown in the Nebraska tables due to the difference in the number of years that have been used in computing the cost per mile per year.

The summary of maintenance costs for Nebraska and Kansas given in Table 11 was compiled from the weighted averages of expenditures shown in Tables 2 to 10, inclusive, for Nebraska and in Tables 12, 13 and 14 for Kansas.

Under the heading giving the approximate cost per mile per year for maintenance of surface, the column headed "Routine" has been considered as covering the same operations as the third column from the right in the Kansas tables. The column headed "Special," which includes both reconstruction and sealing, has been considered the same as the Kansas term "Resurfacing" which was obtained as the difference between the second and third columns from the right in the Kansas tables. The column headed "Total" has been considered as covering the same operations as the second column from the right in the Kansas tables. The last column of Table 11 has been considered as covering the same maintenance costs as those shown in the last column of the Kansas tables. All values shown are for weighted average of expenditures for the mileage shown, except as noted.

Analysis of Failures

The most common failures of bituminous surfaces in Nebraska may be divided into three broad classes: (1) failures of the bituminous wearing surface, (2) failures of the bituminous mat, and (3) failures of the subgrade or base.

Failures of the bituminous wearing surface are usually caused by a low bitumen content in the mix or by the type and action of traffic. The bitumen may lack cementitiousness or it may not adhere to the aggregate because of some surface characteristic of the aggregate. Bituminous sand roads on which SC types of asphaltic oils are used are subject to surface disintegration due to hoof marks of cattle and horses. Properly areated MC or RC asphaltic materials in bituminous sand are not subject to this action except immediately after construction. Tractor wheels and crawler-type tractor trucks and some types of farm machinery cause surface failures on short sections of bituminous surfaces.

Failures of the bituminous mat should include all failures within the mat that might occur had the mat been placed on a solid foundation. The most common cause for this type of failure is a deficiency of bitumen which allows the mat to disintegrate due to traffic load and impact.

Other failures of the mat which may be due either to faulty design or construction include: the use of inferior or improperly graded aggregates including fillers; the wrong type, or an excessive amount, of asphaltic material; the use of an inferior asphaltic material; and the presence of moisture in the mat. Excessive cracking of a mat may result from a deficiency of bitumen even though the surface of the mat is sealed. Failures of mats due to the presence of moisture in the mat are common, but not as frequent as is generally thought. A number of failures classed as moisture in the mat are in reality due to moisture between the mat and the subgrade. Failures due primarily to an excess of bitumen are rare.

Some failures have occurred due to lack of aeration where cutbacks have been used and due to the increased use of MC and RC asphaltic oils. Even though special precautions are being taken to insure thorough aeration during construction, there is still some possibility of an increase in this type of failure. This will be particularly true where construction is continued during cold weather. The consistency of the asphalt in place in the mat, the proportion of asphalt and material passing the 200-mesh sieve in the mix, and the fineness and surface texture of the material passing the 200-mesh sieve are the main factors to be considered in the design, construction or reconstruction of bituminous mixtures containing smooth sand or gravel aggregate graded to produce dense mixtures.

Failures of the base and subgrade are the most common cause for the need of special maintenance, and this class of failures is the most difficult to handle. Failures of the mat invariably occur after a failure of the base. Any change in the dry bulk density of the base or subgrade is immediately reflected in the smoothness of the bituminous surface. A change in density may be due either to shrinkage or to swelling of the subgrade or base.

Small changes in moisture content often cause a considerable decrease in the supporting power of the subgrade or base. A small increase in the moisture content of expansive types of soils (clays and silts) may be sufficient to bring the soil to the critical moisture content, while a small decrease, as low as two per cent, is sufficient to cause non-expansive soils (sands) to lose the greater part of their supporting power. The decrease in moisture content of sand subgrades has caused extensive failures on bituminous sand roads in Nebraska during the past two years.

Subgrade failures due to frost boils and soft spots caused by drainage interference are comparatively few in number, but they generally require a considerable amount of investigation in proportion to their extent in order to make permanent repairs.

Another type of failure which occurs in bituminous surfaces in Nebraska that has not been previously mentioned is a failure that occurs in the plane between the bituminous mat and the base or subgrade. This type of failure may be due to several causes. A thin layer of loose material may be present under the prime coat or between the prime coat and the mat which may have resulted from the construction method used, or to the presence of loose material under the mat caused by vibration or impact. There may also be a lack of frictional material at the bonding surface due to the lack of base stabilization, faulty design, or to segregation during manipulation. Failures due to these causes may appear at any time of the year and are not dependent on moisture conditions.

Accumulation and condensation of moisture vapor directly under the mat causes a separation of the mat and base, and results in slippage, shoves and corrugations in the bituminous mat. This condition is very often attributed to moisture in the mat proper.

Displacement of the mat from this cause is most apparent in thin mats during a long period of hot, dry weather. This type of failure may occur and continue to occur while the subgrade and mat are quite stable.

After failures are apparent in a bituminous surface it is not always possible to immediately make permanent repairs such as an analysis of the condition might indicate was necessary. It is often necessary to make temporary repairs due to lack of sufficient funds, inability to obtain suitable equipment, the large volume of maintenance to be taken care of, or to the lack of suitable detours.

Kansas reports that in their analysis of failures of bituminous surfaces, studies are made of the soils and the oil specifications. No information is given on the classification of failures. To prevent raveling they use thickened edges and resort to shoulder treatments. As to the kinds of failures incurred, they report that true subgrade failures, such as frost boils or insufficient drainage to prevent development of normal subgrade strength under anticipated moisture conditions, are very prevalent. Foundation failures of uncompacted sections occur at approaches to culverts and bridges. Failures due to lean mixtures are reported as rare, and failures due to water and rich mixtures are usually a combination of the two. Some failures are also occasioned by tractors, narrow steel-tired wheels, and live stock.

Correction of Failures—Engineering Policies and Field Methods Used

In Nebraska previous to 1935 it was the policy to seal bituminous surfaces only when considerable indication of raveling was apparent. All sealing done prior to 1935 was done as a maintenance item. In 1935 all mats which were constructed in 1934 and not sealed immediately as a part of the original construction were sealed with construction funds. This year all but three of the projects constructed in 1935 were sealed as part of the construction.

In the maintenance of bituminous mats the present policy is to seal all mats which show any deficiency in bitumen immediately after construction.

For mats having a high density with smooth, tight surfaces a seal coat of RC-2 or RC-1 is applied at the rate of .15 to .20 gallon per square yard. This is covered with about fifteen pounds per square yard of medium sand gravel or armor coat aggregate. On mats containing coarse material or having a rough surface an RC-2 or RC-3 seal coat of .20 to .30 gallon per square yard is applied and covered with approximately twenty-five pounds of coarse concrete aggregate per square yard.

Prior to 1936 all cover material was stockpiled in small piles located at short intervals along both shoulders. After the application of oil this was hand spread over the surface. However, a uniform coverage was not always obtained by this method. The state is now using sand-spreaders which are pushed over the freshly oiled surface so that the sand is spread ahead of any equipment passing over the freshly oiled surface. The aggregate is dumped directly into the spreaders and is spread evenly over the surface. This method appears much more satisfactory than the hand method.

On bituminous sand surfaces, which were originally constructed with SC-3 asphaltic oil and which have satisfactory stability, MC-2 asphaltic oil is used for sealing. Generally .20 gallon per square yard is applied, but this quantity must be varied with the season of the year. The cover material used on sealing of bituminous sand surfaces is blow sand which is usually obtained from the roadside. The cover material is not applied until after the penetration of the asphaltic oil is about completed and is then applied in excess of the amount required.

On bituminous sand surfaces originally constructed with cutback asphalts either MC-2 or RC-2 is used as seal material. These surfaces are usually very hard on the surface and subject to considerable cracking due to the lower three inches of the mat remaining soft. The principal reason for sealing these surfaces is to prevent the entrance of sand into the cracks which forms a layer of separation between the upper ½ to ¾ inch of surface and remainder of the mat. Entrance of surface moisture into these cracks has caused no apparent damage during a period of five years.

The only sealing information available on Kansas bituminous surfaces is for their oil penetration surface. In the case of oil penetration the original thin mat is expected to be supplemented each year by surface sealing or resurfacing which is in the nature of an armor coating. The method now in use in Kansas consists of windrowing approximately 115 cubic yards of cover material per mile along the shoulder of the section to be treated. This cover material may be sand gravel, chat or crushed stone. In no case is more than five per cent of the cover material retained on the ¾-inch sieve and not more than five per cent of the sand gravel or crushed stone passes the 8-mesh sieve, while fifteen per cent of the chat may pass the 30-mesh sieve. The blade grader is used for spreading the windrowed material over the oiled surface. The sand-spreader method has been used, but their studies indicate an increase in cost from $40 to $80 per mile and they do not believe the advantages of the sand-spreader over the blade justify this additional cost. However, on narrow roads the use of a sand-spreader may be required due to lack of space for the windrow. After the windrow of cover material has dried, approximately .25 gallon per square yard of MC-2 or MC-3 oil is applied to the surface and immediately covered. Medium curing cutbacks are used during hot weather and rapid curing cutbacks are used in the late fall to prevent excessive bleeding the following spring.

The reworking of bituminous mats in Nebraska is divided into two groups: those which have had little or no special maintenance, and those which have had considerable special maintenance and are again in need of considerable special maintenance.

Bituminous mats which have had little or no special maintenance and which have developed considerable wrinkling or subgrade displacement are torn up, remixed, the base allowed to dry, and then relaid if the bituminous aggregate appears to contain sufficient asphaltic binder to allow the mat to compact. If the mat appears deficient in bitumen, samples are taken at 1000 to 1500-foot intervals, analyzed, and compared to the original sample data for the particular section. RC-2 asphaltic oil is added to the material found deficient in binder for mats originally constructed with SC asphaltic oil. For mats where MC asphaltic oil was originally used, MC oil is added in maintenance operations. If the mat is relaid without the addition of oil, it is generally sealed immediately.

Mats which have had considerable special or routine maintenance and which again need considerable special maintenance are now reconstructed in a different manner. The mat is torn up and stockpiled or windrowed on the shoulders and the subgrade stabilized. This stabilization is based on the subgrade samples taken prior to the original construction or on samples taken prior to tearing up the mat. Generally a stabilized gravel mat is constructed using new materials. In most cases it has been found more economical and more satisfactory not to use binder or other material from the subgrade in the construction of stabilized gravel bases which are to be constructed on expensive types of subgrade soil. The stabilized gravel base is constructed to a thickness of three to five inches on types A-6 or A-7 soils, depending on the height of the fill and the drainage conditions. The depth of stabilization is based on engineering judgment rather than on any engineering formula. Bituminous stabilization is resorted to on sandy and silty soils which are economically suited for that purpose. The depth of this stabilization depends on the quantity of the material in the subgrade soil that passes the 200-mesh sieve. A three-inch depth is generally sufficient where the subgrade soil contains from 20 to 40 per cent of material passing the 200-mesh sieve. A 4 to 5-inch depth is required when the per cent of material passing the 200-mesh sieve is between 10 and 20 per cent. Stabilized gravel bases after compaction are primed with MC-1 asphaltic oil. Bituminous stabilized bases are not primed. The gradation of the bituminous mat is then rectified by the addition of the proper materials and the apshaltic oil content is corrected by the addition of the proper asphaltic oil.

The reworking of bituminous sand surfaces is materially different from the reworking of bituminous mats due to the nature of the subgrade material and the greater thickness of the combined base and surfacing.

Bituminous sand surfaces which are deficient in asphaltic binder are reworked to a depth of two to three inches and after adding the proper quantity and type of asphaltic oil are remixed. Reworking to a depth of less than two inches is an invitation to early failure due to slippage of the top layer on the construction layer below caused by lack of sufficient depth of uniform material to transmit the shearing action of the loaded area.

Bituminous sand surfaces which are low in stability and which have been built on a dry sand subgrade and contain little or no material passing the 200-mesh sieve must have their stability increased to give better load distribution. This involves complete reconstruction and usually the addition of filler material.

Bituminous sand surfaces which have the proper asphalt content, stability and density, and which fail due to displacement of the subgrade, may be reworked to restore the proper cross section as a temeporary maintenance operation.

If the failure was caused by the loss of moisture in the sand subgrade and the moisture content returns to normal (between 3 to 5 per cent) this type of maintenance is effective.

Some of the early mats constructed in Nebraska were only 1¼ to 1½ inches in thickness and when these mats are torn up approximately one-fourth inch of the base material is incorporated with the mat. This material, together with about one-fourth inch of material added by seal coating, increases the thickness of the reworked mat about one-half inch.

As a policy, the thickening of mats is not intended to accompany reconstruction. However, after a mat has been torn up a second time, the addition of gravel is necessary to correct the gradation. The strengths of reworked mats are usually much higher than for mats originally constructed with SC asphaltic oil. This is due to the use of RC asphaltic oil in the reconstruction which fluxes with the SC asphaltic oil and produces a heavier residual asphalt in the mat.

It has been found necessary this season on several bituminous mats to seal surface cracks which were caused by shrinkage of the subgrade. This shrinkage was probably due to the unusually severe winter of the past year and the extreme heat early this season. These cracks occur chiefly on mats where the stability of the bituminous aggregate was very high and the bitumen content low.

Kansas reports that some of their mat failures have been corrected by scarifying the old mat and mixing it with 30 to 50 per cent of the soil subgrade and compacting the mixture with sheepfoot rollers and then penetrating.

Some of their mat failures have been corrected by constructing 6-inch hand sledged or crushed stone bases.

Special Methods and Materials Used in Maintenance

Materials used by Nebraska in the maintenance of bituminous surfaces are the same as those used for construction. Occasionally short experimental sections of bituminous sand surfaces or bituminous mats are reconstructed by using special bituminous materials such as special cutback products, powdered asphalts, emulsions and tars. The only place where a special method of reconstruction using an emulsion has been adopted is on bituminous sand surfaces. The method and material now used were adopted after trying several different methods and using several types of emulsion. The emulsion recommended is a very stable emulsion having an asphalt base of 30-60 penetration. The method of reconstruction used is to scarify a depth of about 1½ inches for a width of nine feet and then apply the straight emulsion to the scarified material and mix immediately. The emulsion does not break for about two hours, which gives sufficient time to secure thorough mixing. The mixed material is windrowed and more material scarified, after which the emulsion is added and the process of mixing and windrowing continued until the top three inches of the surface for the full width has been mixed and windrowed. The mixed material is allowed to remain in the windrow for at least 24 hours before being aerated to remove moisture. The moisture content is reduced to .5 per cent or less before the bituminous sand is laid. An emulsion having a base asphalt of 30-60 penetration is used on the assumption that the original SC asphaltic oil will flux the hard asphalt in the emulsion and produce an asphaltic residue in the bituminous mixture similar to the residue resulting when an MC asphaltic oil is used.

Practically the same results may be obtained from the use of an RC cutback having a low penetration base asphalt. An advantage that is in favor of the use of emulsion is that it can be applied during wet weather. However, the moisture must be removed by aeration before the surface can be relaid.

Powdered asphalt has been tried for reconstruction of bituminous sand surfaces, but has not proven satisfactory, probably due to the quality of oil existing in the material to be reconstructed.

I am informed that Kansas has used a special cutback asphalt product in some of their reconstruction surface sealing. They also report that in Division Four only products meeting the spot test are used. Nebraska specifications permit the use of one group of SC oils that do not meet the spot test requirements, but none of this material has been used during the past two years.

The present trend of maintenance in Nebraska is to pay more attention to the application of engineering principles on reconstruction and to use better field control. More attention is also being given to drainage, height of grade and shoulder reconstruction, which is one of the most vulnerable points of a bituminous surface.

Kansas also reports that shoulder treatment and drainage, along with the construction of thickened edges, cover their present trend of maintenance.

TABLE I

Total Mileage of Bituminous Surfaces and the Approximate Mileage Given Special Maintenance, Nebraska

	Total Mileage of Bituminous Surfaces					Approximate Mileage Given Special Maintenance*											
						Bituminous Mat Surfaces						Bituminous Sand Surfaces					
						Sealed or Light Armor Coated		Torn Up & Relaid Due to Subgrade Failure		Recon-structed Due to Mat Failure		Sealed		Torn Up and Relaid Due to Subgrade Failure		Recon-structed Due to Surfacing Failure	
Year	Bit. Mat Sur-faces 1¼"--3"	Bit. Sand Sur-faces 4"--6" Depth	Bit. Sand Mat Sur-faces 3" Depth	Sur-face Treat-ment on 3" Sta-bilized Base	Bit. Mats Con-structed on Sta-bilized Base	Cons. F'ds	Main F'ds	Cons. F'ds	Main F'ds	Cons. F'ds	Main F'ds	Cons. F'ds	Main. F'ds	Cons. F'ds	Main. F'ds	Cons. F'ds	Main F'ds
1928	5																
1929	5	5															
1930	5	22															
1931	10	82															
1932	116	150							1								
1933**	151	157					30		1				7		2		12.0
1934	362	157					48		15	5	15		11		7		16.5
1935	449	168	21		15	93	31		8		3		32		9	6	5.5
1936	592	204	55	17	160	68	16	5	10	1	4		10		3		10.0
Total	592	204	55	17	160	161	125	5	35	6	22		60		21	6	44.0

Total mileage of bituminous surfacing under maintenance exclusive of 1936 construction..............638
Grand total miles of bituminous surfacing including 1936 planned construction..............868

Summary of Total Mileage Given Special Maintenance Which Includes Special Maintenance Performed in 1936.

Total Bituminous Mat Sealed	286 miles of a total of 449 miles.
Total Bituminous Sand Sealed	60 miles of a total of 189 miles.
Total Bituminous Mat Torn Up and Relaid	40 miles of a total of 449 miles.
Total Bituminous Sand Torn Up and Relaid	21 miles of a total of 189 miles.
Total Bituminous Mat Reconstructed	28 miles of a total of 449 miles.
Total Bituminous Sand Reconstructed	50 miles of a total of 189 miles.
Grand Total Special Maintenance	480 miles of a total of 638 miles.
Grand Total Special Maintenance Less Const. Sealing	319 miles of a total of 638 miles.

*The maintenance mileages shown for any given year are based on the mileage of surfacing that had been constructed prior to that year.

**Includes maintenance in previous years.

TABLE II

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINOUS SAND SURFACES TO JANUARY 1, 1936

Group 1, Surfacing Constructed in 1931 Using Cutback Oil and Subgrade Sand

Project	Patrol	Location	*Condition of Surface	Daily Traffic			Plan Length in Miles	Approximate Original Cost		No. Years Maint. Cost Recorded	Approximate Cost per Mile per Year for Maintenance of Surface			**Av. Total Maint. Cost per Mile per Year
				Cars	Trucks	Total		per Mile	Per Sq. Yd. per Inch of Plan Depth		Routine	Special	Total	
313A	852	O'Neill-South	B-2	337	191	528	9.49	5744	0.117	4.18	39	36	75	337
80D	731	Weir	B-2	207	56	263	6.95	5027	0.119	4.00	19	109[a]	128	357
Group 1, weighted average for 16.44 miles									0.118		31	67	98	345

a Includes two miles of construction of bituminous sand shoulders two feet wide.
* B Signifies good condition with some special maintenance anticipated within the next year.
2 Indicates fair to good riding surface.

**This covers all maintenance expenditures of every kind charged against the patrol as taken from Auditor's Statement.

TABLE III

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINOUS SAND SURFACES TO JANUARY 1, 1936

Group 2. Surfacing Constructed in 1931 Using Road Oil and Subgrade Sand

Project	Patrol	Location	*Condition of Surface	Daily Traffic			Plan Length in Miles	Approximate Original Cost		No. Years Maint. Cost Recorded	Approximate Cost per Mile per Year for Maintenance of Surface			**Av. Total Maint. Cost per Mile per Year
				Cars	Trucks	Total		Per Mile	Per Sq. Yd. per Inch of Plan Depth		Routine	Special	Total	
80E	730	Mullen-West	B-1	207	56	263	6.90	5150	0.084	4.33	21	162[a]	183	330
277F	718	Hyannis-Ashby	B-1	207	56	263	7.97	5150	0.084	4.00	18	238[b]	256	379
681B&C	433	St. Paul-East	C-2	616	164	780	15.60	5050	0.082	4.00	70	244[c]	314	584
233F&G	749	N. Platte-Tryon	C-3	40	14	54	11.70	4250	0.088	4.18	24	46	70	156
Group 2, weighted average for 42.17 miles									0.084		39	175	214	385

a Includes reconstruction of 1.0 miles and tearing up, relaying and sealing of 5.9 miles.
b Includes reconstruction of 4.49 miles and tearing up, relaying and sealing of 3.48 miles.
c Includes reconstruction of 9.9 miles and tearing up, relaying and sealing of 4.0 miles.

* B Signifies good condition with some special maintenance anticipated within the next year.
C Signifies fair to poor condition with considerable special maintenance anticipated within the next year.
1 Indicates excellent riding surface.
2 Indicates fair to good riding surface.

**This covers all maintenance expenditures of every kind charged against the patrol as taken from Auditor's Statement.

TABLE IV

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINOUS SAND SURFACES TO JANUARY 1, 1936

Group 3. Surfacing Constructed in 1932 Using Road Oil, Subgrade Sand and Filler

Project	Patrol	Location	*Condition of Surface	Daily Traffic			Plan Length in Miles	Approximate Original Cost		No. Years Maint. Cost Recorded	Approximate Cost per Mile per Year for Maintenance of Surface			**Av. Total Maint. Cost per Mile per Year
				Cars	Trucks	Total		Per Mile	Per Sq. Yd. per Inch of Plan Depth		Routine	Special	Total	
3	419	Gr. Island-West	A-1	535	130	665	4.30	4830	0.068	2.00	5	249[a]	254	413
202I	871	Valentine-West	B-1	260	80	340	11.31	4650	0.066	3.42	8	12	20	137
317C		Valentine-East	B-2	288	96	384	5.16	4750	0.067					
313E	853	Bartlett-O'Neill	A-1	337	191	528	7.10	4600[c]	0.068	3.00	6	182[b]	188	331
631D	319	Neligh-North	A-1	273	75	348	9.98	3900	0.058	3.00	16	26	42	157
639D	829	Amelia	B-1	195	54	249	12.55	2850	0.090[d]	3.00	6	4	10	89
Group 3, weighted average for 50.40 miles									0.071		9	57	66	180

a Includes sealing entire project 26-foot width.

b Includes sealing entire project 26-foot width. Cost is $21.00 excluding sealing.

c Part State forces and part contract work.

d Actual depth four inches rather than plan depth of three inches, consequently cost per square yard per inch of actual depth would be approximately 0.067.

* A Signifies an excellent condition with no special maintenance anticipated within the next year.
B Signifies good condition with some special maintenance anticipated within the next year.
1 Indicates excellent riding surface.
2 Indicates fair to good riding surface.

**This covers all maintenance expenditures of every kind charged against the patrol as taken from Auditor's Statement.

TABLE V

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINOUS SAND SURFACES TO JANUARY 1, 1936

Group 4, Surfacing Constructed in 1934 Using SC-3 Road Oil, Subgrade Sand and Filler

Project	Patrol	Location	*Condition of Surface	Daily Traffic			Plan Length in Miles	Approximate Original Cost		No. Years Maint. Cost Recorded	Approximate Cost per Mile per Year for Maintenance of Surface			**Av. Total Maint. Cost per Mile per Year
				Cars	Trucks	Total		Per Mile	Per Sq. Yd. per Inch of Plan Depth		Routine	Special	Total	
NRS355A	854	Cummingsville -Elgin	A-1	87	66	153	5.04	6060[a]	0.090	1.17	17	——	17	132
NRH233C	778	N. Platte-Tryon	B-1	40	14	54	5.21	4540	0.077	1.00	6	——	6	133
Group 4, weighted average for 10.25 miles									0.083		11		11	133

a Very high filler cost.

* A Signifies an excellent condition with no special maintenance anticipated within the next year.
B Signifies good condition with some special maintenance anticipated within the next year.
1 Indicates excellent riding surface.

**This covers all maintenance expenditures of every kind charged against the patrol as taken from Auditor's Statement.

TABLE VI

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINOUS SAND SURFACES TO JANUARY 1, 1936

Group 5, Surfacing Constructed in 1934 Using MC-2 Asphaltic Oil, Blow Sand Aggregate and Filler

Project	Patrol	Location	*Condition of Surface	Daily Traffic			Plan Length in Miles	Approximate Original Cost		No. Years Maint. Cost Recorded	Approximate Cost per Mile per Year for Maintenance of Surface			**Av. Total Maint. Cost per Mile per Year
				Cars	Trucks	Total		Per Mile	Per Sq. Yd. per Inch of Plan Depth		Routine	Special	Total	
80B	732	Hecla E. & W.	A-1	207	56	263	6.60	5440	0.156[a]	1.33	5	—	5	119
202A&D	815	Merriman-Leat	A-2	160	39	199	9.19	4340	0.112[b]	1.08	75	—	75[c]	168
Group 5, weighted average for 15.79 miles									0.130		46		46	148

a Over run in depth approximately 20 per cent. Approximate cost per sq. yd. per in. actual depth 0.128. Long filler haul. Completed in early summer.

b No filler added. Selected sandy soil contained sufficient material passing No. 200 sieve. Completed in late fall.

c High cost of surface maintenance on project 202A&D attributed primarily to poor base, non-uniform lay-down and insufficient aeration.

*A Signifies an excellent condition with no special maintenance anticipated within next year.
1 Indicates excellent riding surface.
2 Indicates fair to good riding surface.

**This covers all maintenance expenditures of every kind charged against the patrol as taken from Auditor's Statement.

TABLE VII

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINOUS MATS

Group 6, Bituminous Mat Surfacing Constructed in 1932 Using Road Oil

Project	Patrol	Location	*Condition of Surface	Daily Traffic			Plan Length in Miles	Approximate Original Cost		No. Years Maint. Cost Recorded	Approximate Cost per Mile per Year for Maintenance of Surface			**Av. Total Maint. Cost per Mile per Year
				Cars	Trucks	Total		Per Mile	Per Sq. Yd. per Inch of Plan Depth		Routine	Special	Total	
124BCK	535	Chadron-East	A-1	435	97	532	14.04	2820	0.176	3.3	82	153	235	356
296A 296B	715[a]	Ogallala-Paxton	B-2	2448	432	2880	11.89 6.82	2560 2250	0.091 0.128	2.5	65	215	280	430
175A	116	Chenney-Bennett	B-1	574	65	639	5.87	2660	0.151	3.3	81	224	325	571
147A&B	510	Kimball-East	A-1	963	147	1110	14.81	1690	0.096	3.0	66	150	216	328
14A 158A	826[b]	O'Neill-Atkinson	B-1	410	170	580	1.29 17.37	2830 2310	0.168 0.137	2.3	47	403[c]	450	628
46 254C	623	Cambridge-Indianola	B-2	400	200	600	13.69	1550	0.085	3.0	19	188[d]	207	334[d]
Group 6, weighted average for 85.78 miles									0.125		58	232	290[c]	438

a Due to a slight relocation on Patrol 715 only 18.41 miles were actually maintained.
b Due to adding a curve on Patrol 826 a distance of 18.88 miles was actually maintained.
c Includes cost of reconstructing 12 miles.
d Does not include cost of reconstructing approximately one mile washed out in the Republican River flood of 1935.
e Excluding the cost for 12 miles of reconstruction on project 14A and 158A, this amount would be $245.

* A Signifies an excellent condition with no special maintenance anticipated within the next year.
B Signifies good condition with some special maintenance anticipated within the next year.
1 Indicates excellent riding surface.
2 Indicates fair to good riding surface.

**This covers all maintenance expenditures of every kind charged against the patrol as taken from Auditor's Statement.

TABLE VIII

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINOUS MATS

Group 7, Bituminous Mat Surfacing Constructed in 1933 Using Road Oil

Project	Patrol	Location	*Condition of Surface	Daily Traffic			Plan Length in Miles	Approximate Original Cost		No. Years Maint. Cost Recorded	Approximate Cost per Mile per Year for Maintenance of Surface			**Av. Total per Mile Maint. Cost per Year
				Cars	Trucks	Total		Per Mile	Per Sq. Yd. per Inch of Plan Depth		Routine	Special	Total	
E-260	500	Big Springs-W.	A-1	766	155	921	5.28	1820	0.104	2.40	17	103	120	286
E-149D	508	Sidney-Brownson	B-2	1064	202	1266	10.22	1710	0.106	2.25	57	393[a]	450	562
NRH149E		Brownson-Potter					11.26	2000	0.107					
E-224D	725	Ogallala-Brule	B-1	1064	202	1266	9.00	2140	0.112	2.30	33	263	296	456
NRH284B	707	Anselmo-Dunning	B-1	258	41	299	10.80	2660	0.165	2.00	51	38[b]	89	182
Group 7, weighted average for 46.56 miles									0.121		46	253	299	422

a Approximately eight miles torn up and relaid.
b Two miles sealed.

*A Signifies an excellent condition with no special maintenance anticipated within the next year.
B Signifies good condition with some special maintenance anticipated within the next year.
1 Indicates excellent riding surface.
2 Indicates fair to good riding surface.

**This covers all maintenance expenditures of every kind charged against the patrol as taken from Auditor's Statement.

TABLE IX

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINOUS MATS

Group 8, Bituminous Mat Surfacing Constructed in 1934 Using MC Asphaltic Oil

Project	Patrol	Location	*Condition of Surface	Daily Traffic			Plan Length in Miles	Approximate Original Cost		No. Years Maint. Cost Recorded	Approximate Cost per Mile per Year for Maintenance of Surface				**Av. Total Maint. Cost per Mile per Year
				Cars	Trucks	Total		Per Mile	Per Sq. Yd. per Inch of Plan Depth		Routine	Major	Special Sealing	Total	
282	564	Harrison-West	A-1	190	60	250	9.30	4030	0.191	1.33	27	....	137[a]	164	310
NRH265B	559	Crawford-Whitney	B-1	190	60	250	9.19	2880	0.136	1.25	36	16	168[a]	220	332
NRH and NRM317F	838	Ainsworth-Johnstown	B-1	340	70	410	9.92	4170	0.197	1.17	14	....	144	158	251
NRS332	323	Neligh-North	B-1	273	75	348	3.97	2450	0.125	1.33	53	None	331[a]	384	613
226	226	Milford-Seward	B-2	786	167	953	6.03	3930	0.186	1.42	86	....	......[b]	86	221
NRH79B	526	Minatare-Angora	A-1				6.64	3560	0.138[c]	1.25	38	19	215[a]	272	339
NRH79D		Minatare-Angora		293	98	391	2.04	4370	0.138						
NRH236D		Bayard-North		234	81	315	3.67	4260	0.134						
NRH236A	525	Minatare-Angora	A-1	293	98	391	9.12	3980	0.126 (	1.33	24	4	202[a]	230	306
Group 8, weighted average for 59.88 miles..................								3730	0.158		36	7			
Group 8, weighted average for 53.85 miles..................								3710	0.154		30	8	187	225	332

a Sealing paid from construction funds. This item is not included in the average total maintenance cost per mile per year.

b Sealing costs not available.

c Two different depths constructed.

*A Signifies an excellent condition with no special maintenance anticipated within the next year.
B Signifies good condition with some special maintenance anticipated within the next year.
1 Indicates excellent riding surface.
2 Indicates fair to good riding surface.

**This covers all maintenance expenditures of every kind charged against the patrol as taken from Auditor's Statement.

TABLE X

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINOUS MATS

Group 9, Bituminous Mat Surfacing Constructed in 1934 Using SC-3 Asphaltic Oil

Project	Patrol	Location	*Condition of Surface	Daily Traffic			Plan Length in Miles	Approximate Original Cost		No. Years Maint. Cost Recorded	Approximate Cost per Mile per Year for Maintenance of Surface				**Av. Total Maint. Cost per Mile per Year
												Special			
				Cars	Trucks	Total		Per Mile	Per Sq. Yd. per Inch of Plan Depth		Routine	Major	Sealing	Total	
NRH 29	280	David City-Rising City	B-2	602	164	766	9.31	2740	0.130	1.25	44	11	None	55	191
76A 265M	548	Chadron-South	B-1	424	87	511	7.43 0.25	3560 5010	0.181 0.255	1.00	75	7	257[a]	339	470
NRH124A NRM108B	551	Hay Springs-West	A-1	246	71	317	5.99 0.75	3160 3040	0.150 0.144	1.25	18	None	266[a]	284	384
NRH158B	828	Stuart-Atkinson	B-1	365	115	480	10.49	2870	0.136	1.17	21	48	359[a]	428	563
257A 257B	193	Palmyra-Cheney	B-1	290	39	329	3.12 3.00	2740 2840	0.130 0.134	1.33	58	109	None	167[b]	312
NRH316A NRH316C	512	Bushnell-West	A-1	826	80	906	7.94 0.71	2040 1820	0.097 0.086	1.33	39	2	223[a]	264	352
Group 9, weighted average for 48.99 miles..................								2840	0.137		41	27		262	384
Group 9, weighted average for 33.56 miles (excluding project 29 and project 257A&B)													282		

a Sealing paid from construction funds. This item is not included in the average total maintenance cost per mile per year.

b Does not include cost of reconstruction which was paid from construction funds.

*A Signifies an excellent condition with no special maintenance anticipated within the next year.
B Signifies good condition with some special maintenance anticipated within the next year.
1 Indicates excellent riding surface.
2 Indicates fair to good riding surface.

**This covers all maintenance expenditures of every kind charged against the patrol as taken from Auditor's Statement.

TABLE XI

SUMMARY OF AVERAGE MAINTENANCE COSTS FOR ALL TYPES OF BITUMINOUS SURFACES*

NEBRASKA AND KANSAS

Description of Bituminous Surfaces	Data From Table Number	Miles Represent.	Approximate Original Cost		Approx. Number Years Maint.	Approximate Cost per Mile per Year for Maintenance of Surface			Average Total Maint. Cost per Mile per Year
			Per Mile	Per Sq. Yd. per Inch of Plan Depth		Routine	Special	Total	
NEBRASKA									
1931 Bit. Sand using C. B. Oils	II	16.44	5440	0.118	4	31	67	98	345
1931 Bit. Sand using S. C. Oils	III	42.17	4860	0.084	4	39	175	214	385
1932 Bit. Sand using S. C. Oil and Filler	IV	50.40	4070	0.071	3	9	57	66	180
1934 Bit. Sand using S. C. Oil and Filler	V	10.25	5290	0.083	1	11	0	11	133
1934 Bit. Sand using M. C. Oil and Filler	VI	15.79	4800	0.130	1	46	0	46	148
1932 Bit. Mat using S. C. Oil	VII	85.78	2230	0.125	3	58	232	290	438
1933 Bit. Mat using S. C. Oil	VIII	46.56	2100	0.121	2	46	253	299	422
1934 Bit. Mat using M. C. Oil a	IX	53.85	3710	0.154	1	30	195	225	332b
1934 Bit. Mat using S. C. Oil	X	48.99	2840	0.137	1	41	221c	262	384b
Weighted Average Expenditures for Bituminous Sand (135 miles)			4660	0.088		25	84	110	257
Weighted Average Expenditures for Bituminous Mat (235 miles)			2670	0.133		46	225	271	399
Weighted Average Expenditures for all Types of Bituminous Surfaces (370 miles)			3400	0.117		38	174	185	347
KANSAS									
Heavy Bituminous Mat	XII	47.4	4480		1	101	116d	217	305
Oil Penetration	XIII	170.1	630		1	116	397e	513	594
Light Bituminous Mat	XIV	356.9	1990		1	364	209f	573	665
Weighted Average Expenditures for Heavy and Light Bituminous Mats (404 mi.)			2280			333	198	531	623
Weighted Average Expenditures for all Types of Bituminous Surfaces (574 miles)			1790			269	257	526	614

a Project 226 (6.03 miles) omitted because of incomplete data on sealing cost.

b The cost shown does not include sealing or reconstruction paid from construction funds. See notes on Tables IX and X.

c Approximate average cost of sealing (actual miles sealed) $282.00 per mile per year.

d Approximate average cost of resurfacing (actual miles resurfaced) $238.00 per mile per year.

e Approximate average cost of resurfacing (actual miles resurfaced) $432.00 per mile per year.

f Approximate average cost of resurfacing (actual miles resurfaced) $472.00 per mile per year.

* The values shown in this table were obtained by caluculating the weighted average of expenditures shown in the respective tables covered by Description of Bituminous Surfaces.

TABLE XII

KANSAS MAINTENANCE COSTS
ON
HEAVY MAT FROM PERIOD JULY 1, 1933, TO JUNE 30, 1934

Section Number	Length Miles	24-Hour Traffic	Original Cost per Mile	Routine Maintenance per Mile per Year	Surface Maintenance per Mile per Year	Resurfacing plus Surface Maintenance per Mile per Year	Resurfacing Plus Routine Maintenance per Mile per Yr.
1	16.0	500	3679.65	149.88	72.56	336.56	413.88
2	8.4	567	6489.14	160.69	57.36	57.36	160.69
3	16.0	631	4342.70	167.62	85.59	85.59	167.62
4	7.0	732	4187.50	365.95	253.51	433.51	545.95
	47.4	500 to 732	4674.75 Av.	211.04 Av.	117.26 Av.	228.26 Av.	322.04 Av.

TABLE XIII

KANSAS MAINTENANCE COSTS ON OIL PENETRATION FOR PERIOD JULY 1, 1934, TO JUNE 30, 1935

Section Number	Length Miles	24-Hour Traffic	Original Cost per Mile	Routine Maintenance per Mile per Year	Surface Maintenance per Mile per Year	Resurfacing Plus Surface Maintenance per Mile per Year	Resurfacing Plus Routine Maintenance per Mile per Year
1	19.0	166	921.07	139.47	43.78	323.33	419.02
2	14.0	347	758.12	153.59	81.28	81.28	153.59
3	4.8	349	502.15	209.69	51.58	419.63	577.74
4	10.0	381	436.22	250.57	100.64	566.49	716.42
5	15.5	534	689.53	186.42	91.83	695.66	790.25
6	7.1	539	504.77	252.76	180.31	782.91	855.36
7	19.0	541	523.01	286.26	233.84	419.26	471.68
8	8.2	560	499.72	144.06	110.66	715.53	748.93
9	12.2	590	594.01	128.81	67.77	376.37	437.41
	109.8	166 to 590	603.18 Av.	194.62 Av.	106.85 Av.	486.72 Av.	574.49 Av.
10	12.6	650	505.62	306.11	224.27	606.07	687.91
11	18.7	719	613.87	161.61	55.06	494.50	601.05
12	19.8	806	617.64	181.62	129.27	741.53	793.88
13	9.2	1016	747.20	196.55	126.61	639.81	709.75
	60.3	650 to 1016	621.08 Av.	211.47 Av.	133.80 Av.	620.47 Av.	698.15 Av.

TABLE XIV

KANSAS MAINTENANCE COSTS ON LIGHT MAT FROM PERIOD JULY 1, 1933, TO JUNE 30, 1934

Section Number	Length Miles	24-Hour Traffic	Original Cost per Mile	Routine Maintenance per Mile per Year	Surface Maintenance per Mile per Year	Resurfacing Plus Surface Maintenance per Mile per Year	Resurfacing Plus Routine Maintenance per Mile per Year
1	8.5	204	1677.41	212.29	125.23	125.23	212.29
2	8.7	289	2539.11	323.65	272.87	714.87	765.65
3	15.0	343	2165.41	627.32	558.92	558.92	627.32
4	18.0	369	2353.07	214.29	170.03	170.03	214.29
5	18.7	402	1391.01	672.08	587.52	587.52	672.08
6	18.0	489	1607.87	782.25	718.08	718.08	782.25
7	15.0	504	1495.70	502.72	444.35	1059.35	1117.72
8	10.0	534	1113.41	682.75	575.30	575.30	682.75
9	12.8	560	2064.27	475.86	310.70	597.57	762.73
10	9.8	572	2577.92	306.09	215.89	215.89	306.09
11	9.8	597	1834.20	284.56	240.86	240.86	284.56
	144.3	204 to 597	1892.67 Av.	462.17 Av.	383.61 Av.	505.78 Av.	584.34 Av.
12	9.5	620	1891.96	768.14	667.59	667.59	768.14
13	15.0	634	1987.56	606.18	340.98	340.98	606.18
14	14.0	640	2384.30	305.86	239.89	239.89	305.86
15	10.0	647	1699.01	225.00	71.27	482.21	635.94
16	13.0	787	2136.68	425.35	247.65	737.65	915.35
17	20.5	801	2587.21	451.65	400.61	400.61	451.65
	82.0	620 to 801	2114.45 Av.	463.70 Av.	328.00 Av.	478.16 Av.	613.85 Av.
18	14.4	1023	1437.90	540.81	496.16	999.16	1043.81
19	11.2	1054	1914.29	296.25	158.24	575.77	713.78
20	17.4	1140	2435.62	497.96	433.88	952.88	1016.96
21	5.3	1154	2527.99	224.11	145.26	145.26	224.11
22	13.0	1257	937.59	546.23	446.98	1379.69	1478.94
23	13.5	1270	1808.06	347.39	225.93	532.69	654.15
24	7.0	1501	2550.64	602.75	522.70	702.20	782.25
25	15.0	1604	3042.99	246.43	143.59	662.59	765.43
26	10.5	1616	2100.82	114.38	44.60	44.60	114.38
27	7.5	1719	2637.29	536.59	463.52	604.02	677.09
28	15.8	2028	1380.24	529.56	474.62	474.62	529.56
	130.6	1023 to 2028	2070.31 Av.	407.50 Av.	323.23 Av.	643.04 Av.	727.31 Av.

MAINTENANCE OF BITUMINOUS SURFACES IN THE NORTHERN ROCKY MOUNTAIN DISTRICT

Which Is Comprised of the States of Idaho, Wyoming, Utah and Montana.

D. L. Cheney, Bituminous Engineer
Montana State Highway Commission

The maintenance of bituminous surfaces in the northern Rocky Mountain district presents many problems of rapidly growing interest and concern. In general the climatic conditions throughout the district are similar and impose a severe handicap on the highway maintenance men, particularly as their work is directed toward the repair and upkeep of bituminous treated surfaces. Heavy snowfalls, extremes of temperature and moisture, a wide variety of types of construction and surfacing aggregates, and large mileages of unconnected highways, in many instances through sparsely settled areas and far from the sources of supplies, all combine to make this feature of our maintenance work novel, arduous and complex.

The various phases of bituminous surface maintenance in this district are far too numerous to be covered in a single paper, but it might be interesting to review briefly the numerous causes of failure, the methods found adaptable to conditions in the several states, and the organization practices governing equipment and personnel.

At the close of the 1935 construction season approximately 8,595 miles of bituminous surfaces had been constructed in this district and the following tabulations will show the mileage by types in each state and in the district, together with the mileage under maintenance:

State	Plant Mix	Road Mix Heavy & Light	Surface Treatment	State Total	Mileage Under Maintenance
Montana	316	1707	1033	3056	3025
Wyoming	315	1945	165	2425	2425
Idaho	141	1567	46	1754	1707
Utah	130	1230	0	1360	1360
District Total	902	6449	1244	8595	8517

The general maintenance procedure used throughout the district is similar in most essential particulars. However, for the purpose of clarification, each state will be dealt with separately insofar as maintenance organization, equipment organization, maintenance mileage, traffic statistics, and special problems and developments are concerned.

Maintenance Organization

Montana:

The State of Montana is divided into ten divisions, each in charge of a division engineer who is responsible for all maintenance work. In each division having 400 miles or over, under maintenance, the division engineer is assisted by a residence maintenance engineer who is directly in charge of all maintenance operations. The resident engineers supervise all regular routine maintenance and are assisted in this work by maintenance foremen who (typically) supervise actual field operations over a territory of from 75 to 150 miles of highway. These foremen are what might be termed the key men of the maintenance organization as they are in direct contact at all times with maintenance sectionmen, repair crews, and all maintenance operations. They have charge of and supervise all crews, with the exception of those assigned to special maintenance. Minor defects in the bituminous surfaces are noted by them and corrected, and all defects of a major or more serious nature which necessitate special consideration and probably special maintenance, are reported by them to the resident engineer. In all divisions having less than 400 miles under maintenance the division engineer is in direct charge and the maintenance foremen report direct to him rather than through a resident engineer.

For the purpose of handling regular routine maintenance over definite sections, sectionmen or patrolmen are located at set intervals throughout the district, each covering a mileage of from 25 to 75 miles, the length of the section being dependent, of course, upon the condition of the roadway and the maintenance required thereon. These men handle with one regular assistant all of the routine maintenance work, such as cleaning culverts, painting guard rails, burning weeds, trimming shoulders, patching the oil surfaces, etc., and when it becomes necessary, additional help is given them. All of the more major operations, such as shouldering, scarifying, remixing, seal coating short sections, and cleaning ditches, which are not large enough to be termed special maintenance and are to be handled by the division forces, are done by crews working out of the division headquarters in charge of the maintenance foreman.

Special maintenance consisting of major tear-up, reconstruction, crushing and placing of gravel sub-base and drainage repair and seal coat oiling over large sections, is handled in most part by special crews sent out from headquarters, each of these crews being in charge of a foreman well qualified to supervise each particular type of work. This foreman reports through the division engineer to the maintenance or bituminous engineer at headquarters.

The headquarters for the state equipment organization are in Helena, where a well equipped shop is operated in charge of the equipment engineer, under the direction of the maintenance engineer, who has charge of all maintenance equipment operated by the highway commission. A shop is also operated in each of the division headquaters, where from two to four mechanics are employed and regular repair work is done, but all the major repair is handled by the headquarters shop. The equipment engineer is assisted by a field equipment superintendent who travels throughout the state and makes frequent inspection of all equipment, reporting results of these inspections to the division engineer and to the equipment engineer. All equipment used in special maintenance work is returned to the headquarters shop for overhaul and repair during the winter. This equipment consists of 3 gravel crushers, 2 complete road mix and penetration oiling outfits made up of motor patrols, distributors, rollers, road brooms, and trucks. Division equipment is held in the division the year round except such units as may need major overhauling or repair and may be transferred to the headquarters shop for such work. This equipment consists of motor patrols, rollers, distributors, road brooms, and trucks.

During the past year an additional equipment unit for bituminous maintenance has been added in each division. The necessity of securing pre-mixed material to be used in patching, especially during the early spring and fall season when the mineral aggregates in the stock piles and the roadway sections to be patched are cold and wet, required an equipment unit of a type which would thoroughly dry the aggregate and also uniformly mix the aggregate and the asphaltic material. Accordingly, a small pugmill equipped with a drier and a mixing unit was designed in the headquarters shop. The batch mixer on this pugmill has a capacity of appriximately .3 cubic yards. The mineral aggregate is transferred from the stock pile into the bucket conveyor, thence to the drier and from there to the batcher, where the oil is added and the mixing is continued until a satisfactory mixture is secured. It is then dropped from the batcher into wheel barrows or transferred on a belt conveyor into trucks. Approximately 25 yards of suitable patching material is mixed in this pugmill in an eight-hour shift. The mill is mounted on a trailer and may be easily transferred about the division as required.

All major maintenance problems in connection with bituminous surfaces are referred by the maintenance foreman or resident engineer to the division engineer who advises the headquarters office and the matter is then referred to the bituminous engineer for an analysis of the trouble and a decision is worked out by the bituminous engineer and the maintenance engineer relative to the correction of the failure. Should the failure be due entirely or in part to material used in the original job, samples of such material are submitted to the testing laboratory for analysis and all materials to be used in the proposed repair are passed on by the testing laboratory. There is no established line of division between special maintenance and routine maintenance other than the amount of cost, the nature of equipment needed, and method of organization required.

Traffic

Following are the results of traffic counts per 16-hour day during the years 1932 and 1935 on U. S. Highway No. 10 running east and west through the south-central and southern section of the state:

Station	1935	1934	1933	1932
At Montana-North Dakota State Line	404	368	391	374
Midway between Glendive and Wibaux	271	308	208	173
Jct. West of Glendive to Glendive	1100	931	855	
At Dawson-Prairie County Line	398	288	197	213
At Custer-Prairie County Line	320	281	219	177
Jct. 5 Mi. N. W. of Billings to Billings	1345	1034	1059	919
At Canyon Creek, 5 Mi. W. of Billings	2343	1784	1528	1381
Jct. N. of Three Forks to Three Forks	787	640	480	408
Jct. at Sappington to Butte	588	251	327	296
Jct. at Nissler to Butte	2081	1881	1855	2111
Jct. at Crackerville to Butte	1394	1221	1091	1225
Jct. at Drummond to Missoula	598	601	567	421
At Missoula-Mineral County Line	597	522	339	300
At Taft near Idaho State Line	685	604	348	300

These counts are fairly representative of the traffic counts on the main highways throughout the state. State-wide traffic increased 5 percent in 1933 over 1932; 20 percent in 1934 over 1933, and 15 percent in 1935 over 1934. The exact figures are not available for the traffic count so far in 1936 but from all indications there will be an increase over 1935 of from 15 percent to 30 percent.

Wyoming:

The State of Wyoming is divided into six districts with a district highway engineer in charge of all maintenance work. Each district engineer has a maintenance supervisor who is directly in charge of maintenance operations.

With the exception of a small mileage of gravelled road, Wyoming has definitely eliminated the patrol system of maintenance in favor of the gang maintenance with larger crews operating from important highway junctions covering large districts. At the present time these state maintenance crews include about 170 trained men and this force is increased as justified by additional work. Maintenance is carried on from 30 principal maintenance gang stations with the crews working about 50 miles in each direction. If the station is located at a junction point the crews operate within a 50-mile radius. Due to the extremely long distances between important junction points, the state has not been able to entirely abandon the patrol system and a few smaller maintenance units of this type are still required between some of the main stations.

Each of the maintenance gang crews is in charge of a foreman and are equipped with such equipment as is necessary to carry out the usual maintenance within the radius of the station. Special bituminous maintenance would be handled by these crews with their equipment unless the damage was of such magnitude that it would be deemed advisable to place the work under contract.

Special maintenance is considered only as replacements made necessary by fire, floods, or other extraordinary causes.

Each highway district has its own repair shop and both minor and major equipment repairs are made in these shops. Although the maintenance equipment used in the different districts varies due to the type of highway and the mileage of surfacing, in general each district operates the following units of equipment: Three or four motor patrols, two to four oil trucks, one to four oil distributors, one to three 5- to 10-ton rollers, ten to fifteen ton-and-one-half trucks, three or four blade graders, 8- 10- and 12-foot, and tar kettles.

At it is necessary to transfer heavy equipment from one point to another within the district, trailer mountings are provided to permit rapid transfers. Early each year the bituminous engineer and the district engineer usually go over all maintenance problems and make recommendations for needed repairs. Maintenance budgets for each district are then set up from these recommendations. Whenever there is any question of quality of materials to be used or a mix design is needed, these matters are referred to the materials engineer. Asphaltic materials used for maintenance are given the same consideration with reference to testing for quality as is given those materials used for construction purposes.

Idaho:

The State of Idaho is divided into five maintenance districts. These districts are in charge of a district engineer who is assisted in all matters pertaining to maintenance by a district maintenance engineer.

All routine maintenance and minor repair jobs such as patching, replacing of treated surfacing after excavation of local areas in the oil mat, or any work of this nature which require operations only on a limited scale with the regular equipment, are handled by local district maintenance operators.

All other work with reference to bituminous maintenance such as tear-up, reworking, remixing, raising sub-base, adding additional gravel, etc., is performed by district oiling crews which are organized and equipped in each district for this special purpose and which operate during the four summer months of each year.

When the maintenance engineer decides that repair work is of too great magnitude to be performed economically or manually by the local district maintenance operators, the work is then performed as special maintenance by the special district oiling crews. These crews are equipped with distributors, harrows, motor patrols, tractors, heaters, rollers, and small trucks, as well as a portable tool house containing full equipment for field repairs.

Equipment for district maintenance operators consist of asphalt heaters, concrete mixers, power-operated pugmills for the purpose of mixing liquid asphalts and mineral aggregates for stock piles, small road rollers and small pull-type distributors.

All bituminous maintenance problems out of the ordinary or which call for special treatment or methods are referred to the materials and oiling engineer.

The materials department passes on all matters involving materials which are used in maintenance operations throughout the state.

Utah:

The State of Utah is divided into six districts, each district in charge of a district engineer who is responsible for all maintenance. These district engineers report direct to the assistant chief highway engineer, who is in charge of maintenance at headquarters. Section foremen with gang crews and regular maintenance district equipment consisting of tar pots, trucks, graders, and power graders, handle all general routine maintenance.

Special maintenance which consists of major repair and reconstruction is handled as a special reconstruction item and is performed by special crews which are either sent out from headquarters or assembled in the district.

All serious failures are referred to the materials engineer for comment and advice and for an analysis of failure. All materials which are to be used in bituminous maintenance are referred to the materials engineer for tests and inspection prior to use.

Bituminous Mileage and Maintenance Statistics By States

The following mileage of bituminous surfaces by states in the district is that mileage constructed or under maintenance at the beginning of the 1936 construction season. The mileage is not available on bituminous construction from that time up to the present date.

Montana:

Montana has constructed a total of 3056 miles of bituminous surfaces. This total is comprised of 316 miles plant mix, 927 miles of 2½-inch to 3-inch road mix, 780 miles of 1½-inch road mix, and 1033 miles of penetration or surface treatment.

Of the total bituminous surfaced mileage, 3025 miles are under maintenance by state forces and are handled by routine maintenance except for those larger sections which, due to poor subgrade construction or other failures, necessitate reconstruction as betterments and are handled by special maintenance. Special maintenance also includes the surface treatment or penetration oiling and road mix oiling of gravel surfaced projects which is done with state funds.

During the 1933 season 180 miles were surface treated and 29 miles were road mixed by state forces under special maintenance. During the 1934 season, 246 miles were surface treated and 70 miles were road mixed by state forces as special maintenance. During the 1935 season, 234 miles were surface treated and 80 miles were road mixed by state force under special maintenance. This mileage includes some reconstruction and repair but the major part of the work done during these three seasons under special maintenance was new work as betterments on gravel surfaced roads.

The present plans and specifications on contract oiling provide for the placing of a seal coat without the use of mineral aggregate cover material as a part to the contract construction. However, this practice was not in force previous to the 1934 season, and during the past year most of the mileage constructed previous to that time has been seal coated under special maintenance.

During the 1935 season a total of 538 miles were seal coated. A very small mileage of seal coating has been done using the armor coat type sealing, and this was done only in that section of the state where frost and sleet storms early in the fall or spring necessitated the use of a non-skid surface.

Definite statistics with regard to the mileage of bituminous surface treatment or reconstruction work each year is not available as a large part of this work is done in short sections as routine maintenance by division forces. However, it is estimated that approximately 100 to 200 miles are re-worked each season. By re-working is meant scarifying, tearing up the existing oil mat, the adding of either more oil or gravel, or both, as indicated by lack of oil in the mat, excess oil in the mat, or other failures which do not necessitate repairs to the subgrade, the repairs being confined only to the oil mat itself.

It is not possible to give the exact mileage of roadway reconstructed per year but during the past three years approximately 30 to 50 miles have been reconstructed annually. This reconstruction has consisted of lowering and widening drainage ditches, widening and raising grade lines, placing additional subbase gravel, widening the gravel section of the roadway by trenching out the earth shoulders on the outside of old 18-foot gravel trench sections, backfilling the shoulders with gravel material, and widening the existing oil mat. This reconstruction is due for the most part to subgrade failures caused by lack of foundation support, shoulder failures caused by lack of adequate reinforcement under the shoulder line of the oil mat, the penetration of moisture into the oil mat and sub-grade through earth shoulders, and raising of the water table or capillarity.

Maintenance Accounting and Costs

All charges under the maintenance department are classified under one of three heads, general maintenance, special maintenance, and betterments.

General maintenance consists of all maintenance work done by regular forces with division equipment and covers blading, dragging, cleaning ditches, removing weeds, all minor repairs to the oiled surface, and other routine items. Special maintenance consists of repairs or replacements involving a large or unusual expense requiring increased force and equipment. Betterments consist of any addition to the original construction or construction of an improved type such as grade raises, line revisions, original oiling, or other change in surface design, and are handled as special maintenance.

STATE OF MONTANA
RECAPITULATION
OF MAINTENANCE COSTS ON BITUMINOUS SURFACED SECTIONS
FISCAL YEAR ENDING JUNE 30, 1936

Maintenance Section	County	Length of Section	Shoulders & Ditches	Snow Removal, Sanding	Centerline Painting & Striping	Oiled Surface Only	All Other Charges Including Supervision, Equip., Overhaul, Repair	Total Maintenance Cost For Section	Average Cost All Maintenance per Mile
1 MA	Beaverhead	95.009	55.55	11.17	5.99	56.26	50.62	17,062.68	179.59
2 MA	Big Horn	79.103	61.55	10.36	1.30	88.67	95.35	20,348.05	257.23
4 MA	Broadwater	58.652	32.86	11.95	5.19	52.06	43.60	10,302.29	175.65
5 MA	Carbon	55.117	16.48	7.31	9.24	64.96	42.91	7,765.88	140.90
7 MC	Cascade	60.871	52.02	27.85	11.00	126.16	64.70	17,148.98	281.73
11 MB	Dawson	23.410	26.06	11.64	11.96	86.65	58.40	4,558.32	194.72
12 MB	Deer Lodge	14.501	60.28	7.40	8.24	76.02	54.21	2,989.30	206.14
16 MC	Gallatin	8.732	9.43	6.93	7.60	9.00	43.99	671.94	76.95
16 MJ	Gallatin	61.803	30.73	10.14	6.52	49.14	71.72	10,398.67	168.26
18 MC	Glacier	21.890	27.82	75.96	5.60	48.74	120.07	6,089.69	278.19
20 MB	Granite	33.839	38.18	12.67	.82	105.14	67.13	7,578.23	223.95
25 MA	Lewis & Clark	49.972	106.85	63.02	15.45	80.01	102.00	18,356.49	367.33
32 MA	Missoula	60.969	39.74	16.41	6.93	166.60	89.93	19,486.07	319.61
32 MB	Missoula	31.777	35.89	17.17	3.03	184.80	66.81	9,778.09	307.71
34 MA	Park	30.28	31.38	22.39	13.04	58.09	89.78	6,500.67	214.68
37 MA	Pondera	31.928	25.90	5.58	8.76	45.01	55.98	4,509.09	141.23
37 MB	Pondera	20.982	18.22	35.39	4.25	103.05	39.83	4,211.89	200.74
39 MA	Powell	34.497	73.72	33.24	6.00	92.87	79.29	9,835.82	285.12
44 MA	Rosebud	40.881	38.03	12.65	10.50	186.68	70.97	13,033.67	318.82
47 MC	Silver Bow	28.733	146.08	6.93	8.73	167.91	36.26	10,513.71	365.91
48 MA	Stillwater	38.613	20.16	14.50	13.49	107.17	43.41	7,673.62	198.73
49 MA	Sweet Grass	37.691	17.51	18.41	15.04	80.62	56.07	7,073.04	187.66
50 MA	Teton	49.444	15.10	33.41	5.03	119.10	53.13	11,163.09	225.77
50 MB	Teton	22.679	15.36	17.27	4.37	84.22	18.81	3,176.06	140.04
52 MA	Treasure	28.876	8.83	12.24	8.27	121.60	68.31	5,667.53	196.27
53 MB	Valley	18.063	62.96	27.43	12.70	34.05	82.84	3,964.25	219.47
56 MB	Yellowstone	19.792	22.51	10.79	8.58	31.10	36.99	2,176.65	109.98

The counties in the state are numbered alphabetically and a section prefix is used to denote the highway route upon which the work is located. In writing the section prefix the county serial number is used first, followed by the letter "M" designating maintenance, and another letter designating the section within the county, thus, 7 MA (B, C, etc.). Following this designation the order number is used to denote the class of work, that is, whether it is general maintenance, special maintenance, or betterment. Code numbers are then used to show the segregation of the work into the various phases. Each year a budget is set up based on recommendations of the division engineer and maintenance engineer, and the actual cost annually is kept of each section according to the type of work performed. Due to the county sections including work of various types constructed at different intervals over a period of years, it is not possible to keep a record of costs by types of construction. This would be possible only if maintenance costs were kept on each separate construction project or type of surface and the amount of work required to keep these costs is not deemed justifiable at present.

The following tabulation contains a summary of maintenance costs, for the fiscal year ending June 30th, 1936, on all maintenance sections in the state which are entirely surfaced with either plant mix, road mix, or penetration type bituminous surfacing. To date costs have not been kept separately on each type of bituminous surface.

Wyoming:

The total mileage of bituminous surfaced roads in Wyoming on January 1st, 1936, was 2425 miles. This mileage was composed of 315 miles of plant mix, 1260 miles of 2½-inch to 3-inch road mix and 165 miles of surface treatments.

All of the bituminous surfaced mileage is under maintenance by state forces and as all maintenance is handled in the same manner and all of the work is performed by the maintenance gang crews, there is no distinction made between routine and special maintenance.

All construction contracts call for the seal coating of the oil mat as a part of the contract, to be placed as soon as the final compaction of the mat is completed. Two thousand, two hundred and forty-five miles of bituminous mileage have been seal coated at one time or another with a straight seal without the use of mineral aggregate cover. These projects are resealed as often as may be deemed ncessary. Approximatly 180 miles have been sealed by the armor coat method to date, and this mileage will be increased each year as the funds become available.

Approximately 60 miles are reworked or reconstructed each year. This mileage can be expected to decrease because of the fact that the older types when so reconditioned are strengthened where necessary and the new construction is being improved through experience and a better selection of construction materials.

Maintenance Costs:

For the purpose of arriving at maintenance costs as well as to simplify the accounting procedure, each county in the state is divided into several maintenance sections. The sections are coordinated with each of the six districts and do not overlap the district boundaries.

Any one of the maintenance sections may include several construction projects which may each be of a different type construction. or have a different type surface, it has not been possible to keep separate costs for each type of surfacing, as to establish separate maintenance costs on each would increase the auditing and accounting out of proportion to the benefits derived.

This, it is evident, is even more true as adjacent projects within a section are brought to the same standard of completed construction.

All labor, equipment (rent and depreciation), and material costs are charged directly to the maintenance section on which used and the total maintenance costs for the section are derived therefrom.

A recapitulation of general maintenance costs by counties, showing the total cost and the average cost per mile for the fiscal year ending March 31, 1936, is shown on the following page.

Lincoln Highway carries the heaviest average traffic which, according to the 1935 traffic census, was 965 cars per 24-hour day. The maximum count on this highway was 1,412 cars. On minimum up to 1,000 cars per 24-hour day, there has been very little difference evident in maintenance costs. The count so far in 1936 is approximately 15 percent higher than for the same period last year.

STATE OF WYOMING

RECAPITULATION

Of General Maintenance—Costs For Fiscal Year Ending March 31st, 1936

COUNTY	Super-vision 40	Right-of-Way 41	Signs 42	Road Bed 43	Bridges 44	Surface 45	Drainage 46	Snow Storage 47	Snow Removal 48	Ice and Floods 49	Miscel-laneous 50	Grand Total	Division of Expenditure			Division of Expenditure			Type and Mileage				Average Cost Per Mile			
													Labor	Equipment	Material	Oil	Gravel	Earth	Oil	Gravel	Earth	Total	Oil	Gravel	Earth	General
ALBANY	1,711.37	1,477.73	719.99	1,898.68	1,003.01	24,355.95	466.31	1,411.60	7,729.53	5.18	124.77	40,904.02	16,331.13	18,440.60	6,132.29	24,715.30	10,258.89	5,929.83	124.15	56.60	14.95	195.70	199.07	181.25	396.64	209.01
BIG HORN	1,646.79	1,617.72	603.04	6,367.08	347.03	14,550.26	1,333.68	40.96	1,008.96		802.61	28,318.13	11,194.84	13,577.60	3,545.69	19,423.33	3,856.28	5,038.52	106.27	20.86	38.73	165.86	182.77	184.86	130.09	170.73
CAMPBELL	1,264.15	2,455.02	259.23	1,206.59	1,145.06	8,777.81	785.27	875.81	4,709 51		101.75	21,580.20	10,241.99	9,757.76	1,580.45	12,951.64		8,628.56	67 29		66.13	133.42	192.47		130.48	161.75
CARBON	2,010.82	2,571.06	949.35	2,491.85	1,259.50	34,666.98	1,471.85	1,354.00	5,581.24	4.81	384.19	52,745.65	19,921.60	22,284.40	10,539.65	42,482.86		10,262.79	177.60		64.57	242.17	239.20		158.94	217.80
CONVERSE	1,078.70	1,185.05	270.43	1,343.62	207.79	4,630.11	292.70	44.59	2,312.39		43 35	11,408.73	4,842.49	5,618.87	947.37	9,077.91	1,650.55	680 27	83.82	6.96	19.13	109.91	108.30	237.15	35.56	103.80
CROOK	2,473.23	2,313.29	167.46	2,645.28	838.95	10,579.68	508.53	1,177.07	4,523.09	25.69	197.38	25,449.65	11,273.02	12,763.11	1,413.52	14,479.83	6,364.56	4,605.26	74.75	26.19	39.37	140.31	193.71	243.01	103.14	181.61
FREMONT	4,119.06	2,910.19	898.59	7,930.87	1,312.93	29,232.45	2,677.60	327.93	3,297.17	137 76	580.65	53,425.20	21,418.65	26,424.84	5,581.71	33,139.07	6,408.79	13,877.34	197.03	24.64	65.66	287.33	168.19	260.10	211.35	185.94
GOSHEN	1,065.05	2,119.86	357.59	2,388.49	214.77	6,755.19	411.80	217.30	713.75		198.26	14,442.06	6,785.60	4,904.07	2,752.39	14,442.06			121.51			121.51	118.85			118.85
HOT SPRINGS	496.24	720.29	350.06	1,607 98	133.18	4,512.04	148.61		931.46		109 61	9,009.47	4,236.49	4,069.18	703.80	7,467.66	1,541.81		36.11	12.73		48.84	206.80	121.12		184.47
JOHNSON	1,362.79	2,073.17	447.47	1,679.03	1,209.80	16,021.26	1,009.96	341.08	3,676.67		112.83	27,934.06	13,024.86	11,345.93	3,563.27	19,947.12	2,320.15	5,666.79	100.27	22 93	26.14	149.34	198.93	101.18	216 79	187.05
LARAMIE	1,445.45	3,082.29	793.59	5,192.41	229.51	15,611.97	630.60	1,815.27	2,322.05		327.34	31,450.48	13,965.26	11,823.86	5,661.36	31,450.48			162.42			162.42	193.64			193.64
LINCOLN	1,946.65	2,294.90	645.44	3,417.89	944.77	21,931.12	2,860.66	938.04	20,088.65	57.09	110.05	55,235.26	21,018.58	32,093.29	2,123 39	16,355.07	35,072.46	3,807.73	83.50	127.47	14.59	225.56	195.87	275.14	260.98	244.88
NATRONA	3,317.34	4,037.17	784.72	9,578.39	958.68	19,633.54	576.61	327.13	5,926.87	143.99	1,018.18	46,302.62	20,206.17	19,898.27	6,198.18	46,302.62			204.56			204.56	226.35			226.35
NIOBRARA	1,453.49	2,622.87	147.43	2,256.78	613.96	10,993.55	622.72	1,044.99	3,445.16	283.94	94.24	23,579.13	11,847.70	9,561.77	2,169.66	23,579.13			126.32			126.32	186.66			186.66
PARK	1,175.41	1,271.29	374.92	3,862.63	212.47	9,833.57	523.91	22.57	2,087.43		336.59	19,700.79	8,346.87	9,895.15	1,458 77	14,489.23	5,211.56		95.89	36.14		132.03	151.10	144.20		149.21
PLATTE	1,112.47	2,651.18	342.69	3,900.20	396.95	10,799.54	688.03	440.56	1,296.30		39.88	21,667.80	10,275 17	7,687 62	3,705.01	18,907.14	2,760.66		104.44	20.43		124.87	181.03	135.13		173.52
SHERIDAN	1,650.92	3,918.90	411.16	3,372.09	1,680.95	17,822.10	1,312.35	296.70	6,167.36		1,118.80	37,751.33	17,052.49	14,569.61	6,129.23	30,053.87	3,726.07	3,971.39	113.99	30 53	28.50	173.02	263.65	122.05	139.35	218.19
SUBLETTE	1,128.68	378.77	231.05	250.61	720.92	13,808.44	761.20	941.12	14,335.61	38.75	84.40	32,679.55	11,199.59	20,514.44	965.52	7,962.15	20,595.58	4,121.82	26.33	96.27	26.83	149.43	302.40	213.94	153 63	218.69
SWEETWATER	1,933.78	2,515.04	990.33	2,292.88	301.40	25,441.19	228.60	885.57	6,266.58	48.17	564.52	41,468.06	16,010.84	17,892.05	7,565.17	41,468.06			218.19			218.19	190.05			190.05
TETON	927.57	235.06	92.52	438.59	1,564.73	8,071.44	359.66	326.00	8,039.90	338.36	54.53	20,448.36	8,197.25	11,790.04	461.07	5,695.36		14,753.00	38.33		61.82	100.15	148.59		238.64	204.18
UINTA	935.30	755.41	444.03	703.95	310.58	11,167.36	455.92	3,368.43	9,683.69	108.62	26.00	27,959.29	10,007.78	11,820.56	6,130.95	25,307.33		2,651.96	78.91		22.46	101.37	320.71		118.07	275.82
WASHAKIE	800.80	1,087.91	409.01	3,884 36	344.21	5,503.55	865.60	20.76	1,465.75	4 14	66.88	14,452.97	6,723.04	6,911.63	818.30	7,047.99	1,724.01	5,680.97	48.61	10.35	22.09	81.05	144.99	166.57	257.17	178.32
WESTON	2,160.44	903.90	181.94	1,094.24	470.19	14,636.52	583.93	835.86	2,883.73		137 81	23,888.56	9,467.87	12,153.51	2,267.18	15,568.69	8,319.87		78.46	32.67		111.13	198.43	254.66		214.96
TOTAL	37,216.50	45,198.07	10,872.04	69,804.49	16,421.34	339,335.62	19,576.00	17,053.34	118,492.85	1,196.50	6,634 62	681,801.37	283,589.28	315,798.16	82.413.93	482,313.90	109,811.24	89,676.23	2,468.75	524.77	510.97	3,504.49	195.37	209.26	175.50	194.60
	5.46%	6.63%	1.59%	10.24%	2.41%	49 77%	2.87%	2.50%	17 38%	0.18%	0.97%	100.00%	41.59%	46.32%	12.09%	70.74%	16.11%	13.15%	70.45%	14.97%	14.58%	100%				

Idaho:

At the close of the 1935 construction season Idaho had constructed 141 miles of plant mix, 1567 miles of road mix and 46 miles of surface treatment, making a total bituminous surfaced mileage of 1,754 miles. Of this mileage 1,707 miles were under maintenance on January 1st, 1936.

There is no definite mileage allotted for special or routine maintenance as the dividing line or control point between the two types is dependent upon the extent of repair and amount of work to be done.

There has been some seal coating done prior to 1934, but the exact mileage figures for this work are not available. However, in 1934, 210 miles were seal coated and in 1935, 355 miles were similarly treated, making a total sealed during these two years of 565 miles.

This sealing is all of the armor coat type, but was done by two different methods, one consisting of an application of approximately .25 gallon per square yard of SC-2 or SC-3 road oil followed by an application of coarse sand, the other consisting of an application of from .2 to .3 gallon per square yard of MC-3 or MC-4 kerosene cutback asphalt, followed by an application of crushed gravel or rock at the rate of approximately 24 pounds per square yard, of which 100 per cent passes a screen having a ¾-inch circular opening and not more than 2 per cent passing the 10-mesh sieve.

Two short projects were seal coated by sealing without the use of cover material, but very poor results were secured.

Exact figures are not available on the amount of reconstruction necessary per year, but it has been necessary to reconstruct a considerable mileage from the years 1932 to 1936 due to the fact that bituminous construction prior to 1931 was placed over many miles of non-standard highway.

Due to labor conditions which have prevailed during the past two years, the cost of reconstruction under maintenance has been materially increased. It is not possible to quote exact costs per mile of reconstruction, as this work is made necessary by a variety of causes which usually call for totally different measures of reconstruction and amount of labor and equipment for the different operations. In 1935 the cost of reconstruction road mix amounted to approximately $1,035 per mile, exclusive of additional gravel material but including the necessary liquid asphalt. During 1935 seal coat oiling performed by state forces cost approximately

$350 per mile, exclusive of mineral aggregate but including liquid asphalt.

Maintenance costs per mile by types are not available as maintenance accounting records are kept by sections rather than projects, and the sections in most instances consist of several types of surfacing, such as concrete, asphaltic concrete, gravel and sand. However, it has been noted that maintenance costs on old bituminous surfaces placed on non-standard highways prior to 1931 have amounted in some instances to almost the original cost of construction. Due to the fact that these projects are likely to be redesigned in the near future and will be accorded the benefit of experience and principles found satisfactory throughout other sections of the state, such sections of the highway system have been maintained in anticipation of their ultimate realignment and reconstruction.

Utah

Utah has constructed 130 miles of plant mix and 1,230 miles of road mix bituminous surface, making a total mileage of 1,360. all of which is under state maintenance.

Special maintenance is performed as a special reconstruction item, and as separate costs are not kept on this item the mileage per year or to date handled by this type of maintenance is not available.

Three hundred and eighty miles have been seal coated in the state, using both a plain seal and the armor coat method.

Maintenance costs are kept by sections as opposed to surface types and as the sections are made up of bituminous surfaced projects, gravel surfaced projects, concrete surfaced projects, and in some instances dirt sections, costs per mile are not available on bituminous maintenance. However, the maintenance budget provides $234.10 per mile annually for all types of surfaces and it is estimated that the actual costs exceed this amount approximately 10 per cent.

Maintenance Engineering Principles and Policies Followed in the District

As time would not permit a visit by the writer to the other states in the district, or the securing of complete information with reference to their bituminous maintenance policies and practices, the following discussion is based primarily on Montana practices and experience but includes the district in general insofar as data was available or could be obtained.

Throughout the district, the district and division engineers play an important part in the analysis of failures in bituminous surfaces, as they are familiar with the territory and locality and all moisture, soil and climatic conditions.

It is the general practice that the district engineer and the bituminous engineer make the investigations and their combined knowledge of general conditions are applied to the causes of failure and suggests the improved method of repair to be used.

Following is the classification of failures and the methods used throughout the district for their correction:

Failures Due to Lack of Load Carrying Ability of the Surface Foundation and Subgrade

These failures are in most part due to lack of adequate base gravel support to reinforce soil conditions or combat a high water table or excessive capillarity which raises the water through the subgrade and up into or near the oil mat;

Excess moisture in the subgrade due to poor drainage and low grade line;

Base gravel containing a high percentage of soils with high capillary attraction;

Soils which rapidly lose their bearing power when they become saturated with moisture;

The construction of bituminous surfaces on low, unstable, poorly drained bases.

Failures of this type are corrected by improving the drainage conditions, raising the profile grade well above the existing water table by placing sufficient base gravel or rock with a minimum amount of soil or filler having a high capillary factor.

In some instances due to excessive sub-surface moisture, French or tile drains are installed to complete the drainage system.

If these failures are of a local rather than general nature and cover only small areas, they are usually repaired by hand by removing from 6 to 24 inches of the existing sub-base material and replacing with rock or crushed gravel and replacing the oil mat.

These failures are being eliminated in the greater part on new construction throughout the district by designing and constructing higher grade lines, increasing the base gravel thickness and extending the base gravel the full width of the grade.

Failures in the Edges of the Oil Mat Due to Lack of Foundation Support

These failures are due in most part to the placing of an oil mat on probably an 18 or 20-foot gravel trench section. That is, the gravel has been placed in a trench 5 to 6 inches deep and 18 feet wide on a 24 to 26-foot roadway, leaving the shoulders outside of the oil mat in the trench section natural soil without reinforcing.

Moisture entering this dirt shoulder, of course, weakens the support under the extreme edge of the mat and continues progressively toward the center.

This is being corrected on sections where the grade line and drainage are satisfactory by blading out the shoulders to the depth of the gravel placed in the trench section and backfilling this section with sub-base rock or gravel so that the full base support extends over the full width of the roadway, and in many instances widening the oil mat out over this newly-reinforced section.

Surface Failures

Failures in the oil mat proper—corrugations, ruts, and softening of the oil mat;

Softening and bleeding of the oil mat due to moisture.

Where these failures occur on a satisfactory and stable base, indicating the entrance of moisture into the mix during construction, entrance of moisture through the surface of the oil mat, or from the shoulders of the roadway, they are corrected by scarifying and taking up the oil mat and reworking it until all moisture has been removed, and relaying and rolling.

In very few instances is it necessary to add oil when reworking sections which have failed due to excess moisture except in instances where the base material becomes incorporated with the mix during the tear-up.

Ravelling Due to Insufficient Asphaltic Material

If this condition is detected in the early stages, it is usually corrected successfully by seal coat oiling, using either plain seal coat or an armor coat.

If it has progressed to such a stage that the mat has become rutted and quite a quantity of thickness displaced, it is patched usually by applying a heavy application of cutback with cover of clean stone and then treated with a seal coat.

In extreme cases the oil mat is scarified and remixed with the addition of more asphaltic material, but these cases are very few as seal coats are used continuously throughout the district whenever they may become necessary.

Excess Asphaltic Material

These failures are in general noted by softening, pushing, rolling, and bleeding in the oil mat. In many instances careful inspection is required to determine whether failure is actually due to excess asphaltic material or to the presence of moisture in the mat which may be displacing the asphalt and driving it toward the surface.

When the failure is due only to excess asphaltic material, it is necessary that the mat be scarified and reworked with the addition of such mineral aggregate as may be required to cut down the excess oil content.

Many failures in bituminous mats throughout the district are due to the use of the wrong type of asphaltic material or to the wrong type and grading of mineral aggregate, or a combination of both during the early construction period of bituminous surfaces.

Where these conditions prevail and the subgrade base support and drainage are properly designed, these failures are corrected by remixing and reworking with the addition of a heavy type cutback with or without additional mineral aggregates as may be required.

These failures, though, occur in most part on old projects where generally the entire roadway design is poor and complete reconstruction is usually necessary.

Failure of the Oil Surface to Support and Carry Traffic

In many cases where the base is entirely free from failures of any sort, or where the failures are of a minor nature and easily remedied, advantage is taken of the oxidized oil mat which, although it may not be economical to maintain its original form, may be covered with a retread or additional mat of any desired thickness and many projects which have been treated by this method seem to be very satisfactory. However, in some instances due to disintegration, cracking, and other failures in the mat itself, where a retread would not be suitable, the mat is taken up and reworked with the addition of more suitable mineral aggregates and asphaltic material to give the proper grading and oil content, designed to give increased thickness and greater stability.

Extensive research work, laboratory control and field inspection are at the present time eliminating the greater part of the defects due to improper design.

Slow curing road oils, SC-2, 3 and 4, medium curing kerosene cutback asphalts, MC-2 and 3, and rapid curing naphtha cutback asphalts, RC-1 and 2, are used in general in maintenance work throughout the district, both for seal coat oiling and for mixing and patching.

During the early construction period of bituminous surfaces and up until the past two seasons, oil-treated stock piles were placed along the roadway for maintenance purposes at the time of construction of the surface. Slow curing road oils were used in the mixes and as on sections where very little maintenance was required during the first two or three years following construction these stock piles through oxidation, weathering, and other causes, became unsuitable for use without the addition of asphaltic material and in some cases mineral aggregate to correct the grading. This practice is being discontinued generally and untreated gravel stock piles are being placed as a part of the construction contract or by maintenance forces as they may be required. For this purpose small portable mixers and pugmills are used, making it possible to have correctly proportioned, freshly mixed material on hand for patching operations. As only the amount of material required for immediate use is mixed, which makes possible the use of heavier asphaltic materials, MC-2 and MC-3 grades of kerosene cutback asphalt are rapidly gaining favor for use in this phase of maintenance.

For repairing thin or shallow depressions in localized areas, caused by mutilative traffic, general wear, raveling or settlement, patches are generally built up by the lamination method; that is, the area to be repaired is treated with a fairly heavy application of asphaltic material, usually MC-2 kerosene cutback asphalt or RC-2 naphtha cutback asphalt. This is followed by a cover of graded aggregate or stone chips. Should one application not build up the depression to the required mat line, continued laminations are built up by the same method.

On sections where sub-base conditions are satisfactory, kerosene cutbacks generally are used for patching and remixing, but on other sections where repair is of a more temporary nature, such as sections on which it is expected that reconstruction work will be done and the repair work is only of such nature that will permit the passage of traffic and keep the roadway in the best possible shape until such time as major repair is effected, the use of the slow curing oils is favored.

SC-3 and SC-4 road oils and RC-2 naphtha cutback asphalt are used for sealing operations of the armor coat type, and RC-1 naphtha cutback asphalt is used mainly for the plain type sealing.

A need was felt during the 1934 season for a seal coat material having a faster drying and curing rate, better penetration, and producing a more resistant, tougher surface than any material being used for seal coat purposes at that time.

The combined efforts of the Montana State Highway Commission and others interested in working out a specification for the desired material resulted in a specification which was built around the four following governing points:

1. Rapid drying and curing properties.
2. Proper penetration and binding quality.
3. Flash point complying with I.C.C. regulations, namely 80 degrees F.
4. Material that could be economically manufactured by refiners.

By controlling the naphtha cut used as a solvent, it was possible to obtain material with an extremely rapid drying rate and good penetration and still hold the flash point above the 80 degrees F. minimum. Base stock used to meet the requirements of this material was considerably harder than had been formerly called for in most specifications governing the manufacture of the cutback asphalt of this type and in addition to developing a material which was very suitable as a special seal, an extremely tough asphalt of unusual characteristics, 100 plus ductility at the 20-40 penetration range, was developed which could also be used in various maintenance operations other than sealing, as it was found that this material could be used for mixing with aggregates for patching during the summer season without the necessity of heating, and in the case of thin patches built up by laminations of asphaltic material and mineral aggregate this material produced a patch which was very durable and resistant to traffic wear and moisture.

The present Montana specifications known as RC-1 Extralight, deviate to a slight extent to suit economical conditions in the state from the original specifications, but this material has been used over a considerable mileage of plain seal coat oiling during the past few seasons and also for general maintenance work and has proven satisfactory in both instances.

Snow Removal

Snow removal plays a very important part in the maintenance of bituminous surfaces. This has been realized rapidly during the past two or three seasons due to the increase of bituminous surfaced mileage.

The removal of snow from the shoulders of the roadway is of particular value, as snow plowed off the traveled way and allowed to melt on the shoulders is in a large part responsible for failures of the mat edges, sub-base saturations, and other types of break-up.

On sections where the seal coat may be worn or not adequate as a waterproofing measure, the continued melting of snow results often in a complete saturation of the oil mat, necessitating in most instances major repair.

While the removal of snow from the entire roadway, of course, increases the cost of this item of maintenance, it is felt that future maintenance costs will be greatly reduced and it is fast becoming the general practice to remove the snow insofar as possible from the entire roadbed and out over the shoulders.

CHANGES IN FIELD PRACTICE OF THE TEXAS HIGHWAY DEPARTMENT IN THE MAINTENANCE OF BITUMINOUS SURFACES DURING THE PAST SIX YEARS

By J. B. Early, Maintenance Engineer,
Texas State Highway Department

The subject of maintenance of bituminous surfaces is too broad—even within the limits of a single state—to be covered in a brief paper. With a multitude of asphaltic and coal tar products designed and produced for highway purposes; with stone and gravel of various quality and gradation in use, and with the resultant innumerable combinations of these materials, it would be a very difficult, if not impossible task, to discuss asphaltic mixtures from a general viewpoint. Frequently, the large number of products within a single state makes standardization of specifications a difficult undertaking.

For these reasons, and because we cannot at this time talk from a general viewpoint with reference to materials for bituminous surfacing, we are going to discuss only the physical development and change of field operations that have taken place in the maintenance of bituminous surfaces on Texas highways during the past six years.

We do not claim originality for any development of practices that may be mentioned. In fact, our first research and resultant major change in field maintenance methods were based on methods previously established in some of the Eastern states. The State of Virginia largely contributed to the first progressive step in our research hereinafter discussed.

Prior to 1930 all repairs to asphalt surfaces were made using the penetration method. Engineers were in agreement that penetration patching work was costly in both labor and material. They recognized the difficulty of securing satisfactory and uniform work where time and weather conditions exerted so much control in the curing of patches made with hot asphalt applied directly to the material on the road.

Added to these objectionable features was the inability to properly proportion the asphaltic content when poured or sprayed onto the filler material. A little too much asphalt meant bleeding with arrival of hot weather. Adding stone or gravel to stop this bleeding often meant raising the patch above the surrounding area, thus creating an unpleasant bump where there had been a hole before.

Penetration patching often referred to as "kettle patching" was a clumsy operation, requiring so much equipment and so much handling of material on the road that it always offered a nuisance and, in many cases, a definite hazard to the safety of highway traffic. This equipment, usually consisting of a large truck loaded with drums of asphalt and pulling a smoking and steaming kettle, would block at least one-half the road. Then there were trucks attending the outfit to haul cover material, which meant further blocking and further hazard to the passing motorist.

It was primarily an effort to get rid of this objectionable method and to eliminate hazards to traffic that first started our experimental work with the premix material. We felt certain that if we could produce a material which could be used both in cold and hot weather, we would be able to secure more uniform maintenance and eventually reduce the cost of keeping asphalt surfaces repaired. We knew that any method which would eliminate time curing was certain to be more economical once the method had been perfected. Based on this assumption, our first research and experiments were not made in an effort to use cheaper materials, but were chiefly concerned with the development of a material which could be manufactured off the road and hauled and placed at any season of the year.

Our first experimental work was the placing of a number of patches of varying thickness using a commercial grade of cutback asphalt with crushed stone aggregate. The asphalt used was a rapid curing cutback having a penetration of residue of about 60 and composed of about 60 per cent pure asphalt and 40 per cent light volatiles. These patches were placed in two courses; the stone in the base course was graded from 1¼ inches to ¾ inch and the surface course from ½ inch to 10 mesh. The proportion of bituminous material in different patches was varied from 2 to 4½ per cent in the base course and from 2½ to 6 per cent in the surface course. These were the net bitumen contents and not the percentages of cutback asphalt used. Accurate unit costs of this work were kept and these costs indicated that if a satisfactory material could be produced, the use of a cold mix asphaltic patching material would materially lower maintenance costs.

Each of these patches was marked and inspected periodically in an effort to determine the most satisfactory mixture. Information obtained in this way indicated that the asphalt used was of too low a penetration, causing the surface to be rigid and brittle. The patches with low bitumen content raveled, especially around the edges. They were too open to properly waterproof the area repaired.

From the observations in this first experiment we placed the next patches with stone from 1¼ inches to ¼ inch for base course and from ½ inch to 50 mesh for the surface course. This grading secured a denser pavement and allowed the surface course to be "feather-edged" more satisfactorily. We also used a higher penetration residue cutback asphalt in the next experiment. A rapid curing cutback within the limits of the Asphalt Institute Specification for RC-2 was used. The penetration of residue was from 70 to 100 and the asphaltic content of the cutback asphalt was slightly higher than that in the first material used.

At the time this research was started many of the asphalt surfaces on highways adjacent to Austin were very irregular and some of them had developed an excessive crown. Using the aggregate and asphalt just mentioned, we began placing heavy patches on the depressions and along the edges of these pavements. Various asphaltic contents were used and the results noted. The upper and lower limits of the aggregate just given

(1¼ inches to ¼ inch and ½ inch to 50 mesh) proved to be satisfactory and the proper gradings on the intermediate screens were developed. From results obtained in these earlier experiments it was found the leveling or first course should have a bitumen content from 3.75% to 4.25% and the wearing course should have a bitumen content of from 5% to 6.5%. When less than these amounts were used, satisfactory results were not obtained.

We were able to secure a more uniform mix and lessen the cost of the mix by pre-heating the cutback asphalt to a temperature of 150 degrees. The flash point of the cutback asphalt is low, but so long as the gas from the naphtha in it is not confined in a closed place we believe that there is no danger in heating the material to 150 degrees. An open flame should never be allowed near the dome of the tank car or the cap of a storage tank.

In placing cold mix asphaltic concrete surfacing or patches it was found that a prime or tack coat was essential in order to secure the best results. For patches a prime coat composed of cutback asphalt of the same specification as used in the mix, diluted with sufficient kerosene to make it pour and spread satisfactorily, was used. This was poured onto the surface to be patched and squeegeed or broomed until a thin coating over the entire surface was obtained. (In placing a surface over an extended area the prime coat should be placed with a distributor at the rate of about .15 gallon per square yard.) After a patch on an old asphalt surface had been placed, it was found better results could be secured by pouring a small amount of the prime coat material on the edge of the patch. This prevented raveling at the juncture of the patch and old surface.

In brief, the results of our experiments in the use of cold premix material have been very gratifying. With its use stable smooth patches on asphalt surfaces have been secured at less cost than unsatisfactory patches were previously secured with penetration methods. This material has proven very satisfactory for leveling up irregular pavements, super-elevating curves, and for all other purposes requiring a smooth, uniform surface. Considerable mileage of this mixture has been placed on new bases and as a surface course on old pavements, by maintenance forces and through regular construction contracts. We believe the results secured have been satisfactory. There are numerous heavy patches on pavements in the vicinity of Austin which were placed four years ago and which show no signs of disintegration. We believe that with the use of a higher penetration residual cutback asphalt (penetration of residue 165 to 195) the most satisfactory results have been obtained and that this class of asphalt will be used more extensively than those with a low penetration residue. We have found no tendency to shove or lack of stability in surfaces where the cutback asphalt of higher penetration residue has been used.

During the same period that tests and experiments were being made with the mixtures composed of crushed stone, sand, and stone screenings and cutback asphalt binder, many other aggregates were tested. Some good results were secured with certain classes of gravel, especially crushed limestone gravel, which makes a satisfactory aggregate. To date, we have not found siliceous gravels entirely satisfactory for this class of work. On tests in which they were used the asphaltic content had to be increased and even with such increase the results were not equal to those in which stone or limestone gravel was the base aggregate. However, we believe continued research will result in eventually developing a satisfactory mixture using flint or siliceous gravels.

We have not attempted to cover in the preceding discussion certain phases of our tests such as the use of rock asphalt dust in small mixtures. This material, mined in large quantities in Texas, has a prominent part in our maintenance program. Discussion of its behavior is omitted because of its inaccessibility to the large majority of states.

Discussion of asphalt emulsions has been omitted because the Texas Highway Department's use of this type of bituminous material has not been sufficiently extensive to permit definite conclusions as to whether or not it is comparable with other types of asphaltic cements. During the past year several of our division engineers have initiated experiments with various emulsions, both in premix and road mix methods. From these and other test projects, we will eventually be able to draw our own conclusions on the economic relativity of cutback asphalts to emulsion products—a subject which we have found to be highly controversial not only among manufacturers of these products but also among many highway engineers.

In conclusion, we may state that the past six years has seen an almost extinction of penetration methods in the maintenance of bituminous surfaces in Texas. One may travel for days over thousands of miles of Texas highways without encountering an "asphalt kettle" patching crew. Time and traffic curing have been eliminated, giving the motorist a maintained road free from flying cover material that breaks windshields, and a road free from excess pools of asphalt which spatter cars and make enemies of the users of the highways who provide the revenue with which we must operate.

REPORT OF NEW MEXICO ON BITUMINOUS MAINTENANCE

By L. C. Campbell, Materials Engineer,
New Mexico Highway Department

1. Preliminary:

This report covers the State of New Mexico only.

Approximate mileage under maintenance to July 1, 1936: 1,150 miles.

Approximate cost per mile per year: $200 average.

Approximate time under maintenance: 50 months average.

The above figures are not given with the idea that they are of statistical accuracy but are merely approximations bringing the maintenance mileage and costs up to date with sufficient accuracy to describe conditions and with sufficient accuracy for the purpose of this report.

2. Maintenance Organization:

Headed by an assistant state highway engineer in charge of all maintenance.

Next and under the above are the five district engineers, under whose direct supervision are the maintenance foremen and patrols. The number of patrols varies according to the needs of routine or special work. The equipment used is that typically required for such work. The laboratory is consulted only when the trouble is not readily solved and remedied in the field.

3. Organization Policies:

There are no particular policies in connection with this maintenance work; the patrolmen find the unsatisfactory condition and repair it and also repair the factors causing or contributing to the condition if they are of such nature and magnitude as to permit repair during routine operation. Anything of sufficient magnitude to require special or prolonged attention is cared for by crews specially detailed to care for the situation.

4. Maintenance Statistics and Costs:

To the data given under "Preliminary" little can be added except minor detail not believed to be of interest or importance for the purpose of this paper.

5. Maintenance Engineering Principles and Policies:

No regular classification of failures or unsatisfactory conditions is used. The routine of patrols for the most part is the stitch in time that prevents the development of anything serious except in rare instances, in the bituminous surface. Poor drainage and poor foundation is avoided and/or remedied as far as is reasonably possible as soon as it becomes evident, and sufficient maintenance is given to keep the surface in smooth riding condition continuously. Sometimes a surface is allowed to go for a while in contemplation of scarifying and retreatment.

STATE OF NEW MEXICO

MAINTENANCE STATISTICS

District	From Completion Date of Original Construction to Jan. 1, 1935					From January 1, 1935 to July 1, 1935		From July 1, 1935 to July 1, 1936	
	Miles	Average Months Under Maintenance	Cost per Mile Roadway Surface	Per Year *Other	Basis Total	Miles	Total Cost per Mile Per Year	Miles	Total Cost per Mile Per Year
1	301.1	47.5	160.08	56.44	216.52			22.67	163.49
2	244.1	42.3	116.02	33.59	149.61	127.95	24.65	171.4	194.85
3	118.45	55.5	198.64	61.22	259.86	157.07	132.5	82.7	265.41
4	238.12	44.15	208.52	66.27	274.79	182.11	339.6	167.0	252.88
5	90.91	42.2	187.14	29.27	216.41	413.58	95.1	94.3	400.92
Average	992.68	45.9	169.30	51.68	220.98	184.63	813.7	742.1	259.65

*NOTE: "Other" maintenance includes Earth Shoulders, Road Sides, Drainage Structures, Road Signs, Snow Removal, Vegetation Removal.

REPORT OF OKLAHOMA FOR THE MAINTENANCE SECTION OF THE MONTANA BITUMINOUS CONFERENCE

By Dudley H. Jones, Maintenance Engineer,
Oklahoma State Highway Department

I. Preliminary:

This paper covers Oklahoma only, which has a state highway mileage of 8,004 miles, and this mileage is maintained through an organization in the field having six complete divisions and a total of 25 maintenance districts within the six divisions. The approximate mileage of bituminous construction now on the state highway system is 1,337 miles.

II. Maintenance Organization:

A. Regularly assigned patrolmen with their crews cover every type of state highway with routine maintenance on the assigned mileage to the patrolmen.

B. Special maintenance handled within a division is under the control of gang patrols not assigned to any road section, but handling various highways and projects as designated by the division engineer or assistant division engineer in charge of maintenance from time to time. This gang patrol work is more highly specialized, and covers work of a nature that the regular patrolman is not usually prepared to handle.

C. All equipment within a division is under the control of the division engineer or his assistant, and this equipment is at all times assigned to various foremen and superintendents, or patrolmen, and the items cover distributors, tank car heaters, caterpillars with blades, motor patrols, pneumatic tractor drawn discs, small cold patch mixers, and trucks.

D. Organization Policies.

1. (a) The responsibility for analysis of trouble and decision as to remedy rests with the division engineer and division maintenance engineer, except in cases where advice is requested from the office at Oklahoma City, which in that case would probably involve the state maintenance engineer and possibly the state materials engineer. (b) All maintenance other than routine does

not go to the materials engineer for comment. However, the materials engineer is requested to make tests and advise in many cases.

2. The control of the division of work between routine and special maintenance lies with the division engineer or his assistant, but this division is practically complete at all times since the special maintenance forces exist and move from job to job as work is needed.

III. **Maintenance Statistics:**

A. Oklahoma has approximately 585 miles of bituminous surface on good gravel or crushed stone bases. This is called our Type No. 2 paving, which is semi-rigid paving, and the greater portion of this mileage is surfaced with either native rock asphalt or one of the various grades of cutback asphalt with local aggregate. There are approximately 752 miles of oil mat road which has some existing base containing metal, but not as heavy as the Type 2 mentioned just above, and the mat proper is nearly all of the dense graded aggregate type, approximately two inches in thickness, compacted above the prime. The mats are built of slow curing oils, medium curing oils, and rapid curing oils, and also probably 100 miles of the above figure is emulsion.

B. 1. The routine bituminous maintenance is handled bv regular patrolmen on their assigned sections. They have trucks for hauling ready mixed patching material. Most of them have the six-foot cold patch mixers and have available light blades that can be pulled with a truck or by hired teams, or by the use of a small tractor secured from the division headquarters. Most of the maintenance by the patrolmen, however, consists of patching with ready mixed material, it being a custom when building oil mat roads, and when reconditioning same, or giving a general overhaul, to stock pile ready mixed material.

2. The special maintenance is handled with gang patrols and with more elaborate equipment, such as necessary motor patrols, heavy trucks, distributors, tank car heaters, and the addition of any needed metal. This type of crew handles practically all sealing work. Very little of the mileage is seal coated on the cutbacks and the emulsion, and this is for the reason that on most of our mats we attempt a very dense grading of aggregate, and no seal is necessary. The native rock asphalt does not need a seal for it is also dense. A fair estimate would be that not over one-fourth

of the mileage has been reworked or reconstructed, and this is mainly for the reason that very few of the oil mat roads are more than five years old, and not many of the Type 2 or rock asphalt on heavy gravel bases are old enough to need much reconstruction.

C. On account of a need of more satisfactory mileage, we have not been able to hold to the type of road that should be constructed in all cases. We have many oil mat roads, costing not over $2,000 per mile, carrying entirely too much traffic, but without the oil mat the road would be a plain gravel road, since funds are never available for the construction of all the rigid type paving needed. Ordinarily we prefer to lay the two-inch oil mats on light gravel bases on roads where the traffic is from 500 to 1,000 vehicles per day. The Type 2 paving, which is the rock asphalt or cutbacks on heavy gravel bases, is preferred on roads with traffic from 800 to 1,500 vehicles per day. For traffic over 1,500 vehicles per day, the more rigid type of paving is preferable. Where money does not permit the more expensive types, we find in that case economy in using bituminous surfaces on the gravel roads, laying the dust, and conserving the metal.

D. Maintenance Costs.

1. The policies followed at the present time in cost keeping is by the distribution of costs in the division offices and also in the central accounting office by patrol sections, the patrol sections being controlled in length only by type and county line boundaries and by division boundaries.

2. Current annual costs by types of maintenance cannot be given for the reason that the distribution of costs has only been installed this year, and figures will not be available for several weeks.

3. Figures are not yet available on projects since initial building.

4. The only general information that can be given with reference to special maintenance costs is that our usual investigation of any particular road indicates that within four or five years the decreased maintenance on a good oil mat will pay for its original construction.

IV. Maintenance Engineering Principles and Policies Followed:

A. Analysis of Failures.

1. General analysis (a and b). No systematic classification of failures is posted or reported, although the division engineering

personnel, together with the engineering personnel of the general office, gives considerable study to any failure and determines the cause. The reworking, or reconditioning, or repairing of any major failure is reported to the general office, inspections nearly always made, and conferences held with the division personnel, and the type and method of repairing is discussed.

(1) Failures due to the lack of load carrying ability rests nearly always with the foundation. The surface usually is satisfactory providing the foundation and subgrade is satisfactory. On all Type 2 paving, such as cutback or rock asphalt on a heavy gravel base, failures are nearly always due to the base, and the writer of this paper would venture that 99 per cent of failures on this semi-rigid type of paving are base failures.

(2) Oklahoma has experienced but little trouble due to raveling, but has experienced considerable trouble with moisture in the mat proper, resulting in transverse corrugations, alligator hiding, or bleeding due to a false excess of total bitumen. Our experience is that an excess of bitumen may cause rutting, but seldom, if ever, transverse corrugations. Water, however, will cause the corrugations more quickly than the longitudinal ruts. We have had some difficulty in training special crews to realize the importance of eliminating water in the aggregate, either in the free state or by absorption in the metal. We have experienced some difficulty due to brittleness, but this is a condition that can be easily corrected with either a slow curing or medium curing road oil, and sometimes can be remedied by the proper seal coat.

(3) Oklahoma seldom experiences frost boils, but we did have some difficulty in the spring this year on a few roads. Most of the base failures are caused by a type of soil that has a high capillary pressure. We have found under the mats, and even under the Type 2 paving, moisture caused mainly by capillary pressure. This state is this year doing some experimental work on base stabilization to prevent moisture in the subgrades. This stabilization is being handled with light, bituminous oils, the proper ditching and draining and in some cases the addition of porous material, such as sand on the gumbos.

2. There is only a small proportion of failures occurring from the inability of the wearing surfaces as a whole to carry the load. Bituminous surfaces either too rich or too lean will usually carry the traffic, although there might be some longtitudinal ruts, and

it is only when moisture is present that there is real trouble with transverse corrugations, and false richness, and softening of the mat.

3. (a) Few failures are caused by frost boils, but frequent failures are due to insufficient drainage, capillary pressure, all of which cause a moisture condition, softening the subgrade.

(b) Foundation failures due to uncompacted sections are very rare. Most of the mats as built by Oklahoma are soft enough to ride with the grade, maybe causing a slight wave in the road, but seldom, if ever, a distinct section. Most of the Oklahoma soils are sufficiently stable when the excessive moisture is eliminated.

(c) Oklahoma has probably experienced all of the usual mat failures; lean mixtures are rare, but on the older mats, four or five years old, it sometimes becomes necessary to recondition the surface. The older mats tend towards hardening and cracking. Water failures are common, and quite often occur in the low ground around culverts or bridge abutments, or on low fills that were originally built of loam soil containing, of course, much organic matter. The water failures are also common where the grade is near solid rock, and in cuts where the grade passes through rock ledges. Under original grading many years ago, the subgrading of the rock, it now appears, was not deep enough. Many corrections are being made now on both existing bituminous surfaced roads and on roads contemplated for future surfacing. Rich mixtures have seldom caused failures in Oklahoma. The control on oil mat work is such that excessive richness is rare. This is true also of the manipulated cutback surfaces. The native rock asphalt is such that it is very rare to even get a spot in the road too rich. We have experienced considerable difficulty in the wheat country from the mutilation of the mats with farm tractors, but we note that there is quite a change in the type of tractors, and nearly all of the new ones purchased have pneumatic tires, and we feel that within a few years this type of failure will be practically eliminated.

B. Correction of Failures.

1. Most of the Type 2 paving, semi-rigid on heavy metal bases, is protected by seal coating, and but little of the true surfacing can be reworked. The oil mats are usually corrected once or twice by remixing and reworking the mat material, but after it has

sufficiently aged, Oklahoma usually goes to the second stage of placing an additional mat or retread.

2. Most of this type of work is handled by the gang patrols, which are special maintenance crews and equipment.

3. Special maintenance materials used:

a. The aggregate in most all cases must be of the dense graded type, from about ¾ inch to and including some 200-mesh for fines. Much of the local gravel in this state is either hard sandstone gravel or limestone gravel. The crushed stone is nearly all crushed limestone. With our type of equipment the bituminous materials for special maintenance are nearly always the road oils, and quite often the medium curing type. Seal work, however, is handled with the rapid curing oil.

V. The trend of maintenance practice in Oklahoma seems to be toward the heavier type of mats, either as original construction or as second stage construction, so as to give an ultimate thickness of oil mat above the prime of some two to three inches. Just a few years ago most of the oil mats were around one to one and one-half inches thick, which is not sufficient for proper maintenance and proper insulation to the roadbed to prevent frost boils and prevent cracking and the entrance of water to the subgrade from above. The trend is also toward motorizing practically everything on oil mat maintenance, even to the making of stock pile materials, hauling to the road, and only placing the material by hand. This hauling from stock piles using prepared materials is usually a temporary expedient to get by from one season to another, filling any holes or raveling that might start. A considerable amount of this kind of work on any road would indicate the need of second stage construction or an entire reconditioning of the surface. There is some trend toward the cutbacks for the typical oil mat road. This oil costs more, but gives more binding or cohesion, and is more resistant to water. On the other hand, the slower curing oils have considerable merit, such as cheapness, and such as being able to recondition or rework a mat within two years of the original construction.

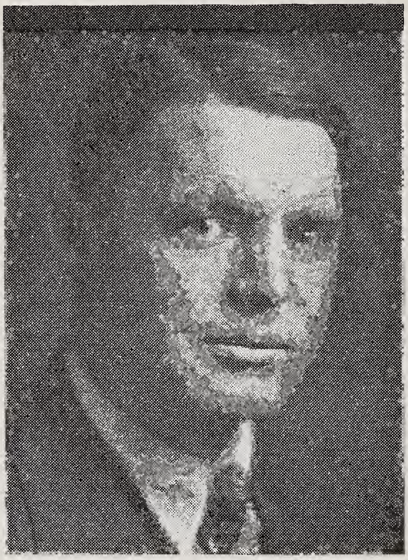
The greater trend outside of maintenance is the increased popularity of bituminous low type road construction. Many communities, towns and counties are asking for this type of work, that just a few years ago was repulsive to liquid road oils.

Another important trend having a bearing on the maintenance of roads of unsatisfactory soil is towards base stabilization with light oils, using something like three to five gallons of oil per square yard of a thickness from five to six inches to stabilize the roadbed ready for future surface treatment. We have a considerable mileage in places where neither clay nor gravel is available, and experimental work has been started this summer on the very sandy soils, and there probably will be a development later in the stabilization of the clays and the gumbos, but no work of this nature will be attempted this year. There is some trend now towards the stabilization or treatment of shoulders on rigid type pavements, not only to protect the shoulders and decrease the maintenance cost, but to eliminate the variation from a rigid paving to a soft, wet shoulder which always causes rutting along the edge of slabs, making driving dangerous and holding traffic to the width of the surfacing.

MAINTENANCE SECTION DISTRICT REPORT

By R. P. Newland, Division Engineer,
Washington State Highway Department

I. Preliminary



District No. 1 comprises the states of California, Oregon and Washington, having a total mileage of bituminous surfaces as follows:

	Miles
California	6,910
Oregon	3,578
Washington	2,166
Total	12,654

II. Maintenance Organization

A. All of the states included use a similar maintenance organization, which is the system of patrol sections. These sections are of varying lengths as determined by the local conditions of terrain and traffic and are manned and equipped to adequately accomplish all routine maintenance work. Washington augments this with a patrolman, or line rider, who carries with him a supply of signs, flags, lanterns, torches and tools necessary for the handling of any small emergency repairs. Each man carries a first aid kit and is thoroughly instructed in its use. His immediate superior, the Supervisor, has a radio-equipped car so that he may be reached from headquarters at any time.

B. Special maintenance is accomplished for the most part by extra gangs, the skeleton organizations of which are always available.

C. Each of the three states maintains an equipment department which rents all major equipment to the routine and special maintenance jobs.

D. Control of the maintenance is in the hands of the Division Engineer (District Engineer in Washington) who, where necessary, secures the assistance and advice of the headquarters organization. The analysis of the trouble and the decision as to the remedy lies with the local Supervisor, the District Maintenance Engineer, the District Engineer or the State Maintenance Engineer, depending upon the nature and seriousness of the particular case in question. The Materials Engineer is regularly consulted on the source of mineral aggregate. He tests all bituminous products used and is called upon further for advice on soils and fillers, when necessary. The definitions of "routine" and "special maintenance" in the various manuals or instructions fairly clearly define the limitations of each class of work and as no definite Special Maintenance organization is carried throughout the entire year, the division of the work as regards forces may at times overlap.

III. **Maintenance Statistics**

A. Bituminous mileages in each state in the district are approximately as follows:

	Calif.	Oregon	Wash.	Total
Light Surface Treatments	1,050	1,969	977	3,996
Plant or Road Mixes	2,510	68	849	3,427
Macadam and Multiple Lifts	1,950	824	269	3,043
Asphaltic Concrete	1,400	717	71	2,188
Totals	6,910*	3,578	2,166	12,654

*Counting rural roads, California reports 12,662 miles (all types) under maintenance.

B. All oiled surfaces in the various state highway systems are given constant definite routine maintenance and special maintenance when and where occasion demands. No data is available as to mileage seal coated. Seal coating is carried on with all types; however, the method defined as "armor coating" predominates. Seal coating is generally considered as a part of any oiling job and mileage statistics are therefore not available. It is correct to assume that all types of light oiling work have been or will be sealed. No available data is at hand on mileages reworked or reconditioned.

C. The writer has been unable to secure any definite data bearing upon the relationship between traffic density and bituminous macadam. Where adequate foundations constructed on well drained bases are present, the factor of density alone does not appear to be serious. Tonnage has greatly increased maintenance through the failure of the oil mat on inadequate foundations and consequent damage to all surfaces during the critical period in the spring due to overloading. In order to hold tonnages within legal limits and to so save excessive maintenance, weighing stations are operated at strategic points throughout the various systems.

D. Maintenance costs are kept in detail on all road sections. These costs, segregated into the various features of roadway, roadside, bridges, drainage, etc., and extending back over a considerable period of time, are available. However, since they have been greatly influenced by many features such as local climatic conditions, soil conditions, volume of traffic, tonnage of traffic, nature of traffic, type of construction, quality of mineral aggregate and quality of asphaltic cement, it would appear that the tabulation of them, unless qualified with extensive explanations beyond the limits of this article, would be apt to be very misleading. The different equipment rental rates in effect in the various states, coupled with the fact that these rates have from time to time been revised, the distances from sources of material and consequent varying costs of asphaltic oil, which costs, due to revisions in the tariffs, have not always been the same, and many other features also make a broad discussion of maintenance costs of very doubtful value.

IV. Maintenance Engineering Principles and Policies Followed in District

A. **Analysis of Failures:** Failures as a general rule are from causes readily identified and their analyses are therefore quite simple. Except for a few isolated instances, these cases may be classified under the two heads of Foundation Failures and Surface Failures, with the former responsible for practically all of the serious trouble.

Raveling can hardly be classified as a failure since its danger is readily anticipated before the condition becomes serious. Allowing this raveling to develop until it can be classed as a failure is evidence of neglect on the part of the regular maintenance organization.

Moisture in the mat (water plus bitumen) is readily identified and is generally a condition to be classified under foundation failure rather than surface failure since it is from foundation weakness that this condition nearly always results.

Excess bitumen is a condition often troublesome but seldom serious. Its presence is obvious.

Brittleness is also readily identified and is generally due to too lean a mix, but also is influenced by the aggregate and is often caused by inferior asphaltic oil. This condition is not common in District No. 1.

Subgrade conditions resulting in failures are, as previously stated, by far the most common and while readily identified, the most practical method of cure is often a difficult problem.

The degree to which maintenance is given to above failures depends entirely upon the funds available and the future reconstruction program. Nearly all oil mats of any appreciable age were constructed upon foundations inadequate for the support of modern tonnages; consequently, the question as to whether a permanent repair of a failure should be attempted or whether it should be given a minimum of attention, merely sufficient to carry it along until the time of reconstruction, is a matter which depends entirely upon the anticipated construction program.

Load support failures are confined generally to the older roads for the reasons mentioned above, and unless these conditions are isolated the problem becomes one of reconstruction rather than one of maintenance.

Due to the almost universal use of pneumatic tired vehicles, the percentage of failures due to mutilative traffic is extremely low. In certain farming districts the use of teams and wagons is continued, while the movement of tractors also presents a problem. The various state laws provide a considerable measure of protection.

B. **Correction of Failures:** Seal coating is more or less universal practice in District No. 1. True seal coating is not generally practiced inasmuch as oils used on the Pacific Coast do not have a tendency to become dead. Hair checking of the surface to the extent that water is allowed to enter the mat is not common.

Armor coating, as defined, is a general practice and has the advantage of a seal together with the additional virtue of strengthening the mat, presenting a uniform appearance and providing a non-skid texture.

Reworking is resorted to where necessary with a definite attempt to cut down as rapidly as possible this class of maintenance due to the attendant annoyance and danger to the traveling public and to the necessity of the ownership of heavy machinery which has only seasonal use.

This reworking is nearly always caused by subgrade conditions, and unless a road is programmed for early reconstruction and in line with the desire to reduce this objectionable feature of maintenance, it is the practice to drain and ballast these sections at the time they are reworked.

Increased thickness is accomplished by the seal as mentioned above, but it is not generally the practice in repair work to make the mat different from that existing on either side of the failure, but rather to correct the cause.

Field methods depend upon the extent of the failure. Minor troubles are handled as a routine matter, while general failures are handled by extra gangs. Patching is done by the use of premix or the penetration method wherever possible in preference to scarification and reconstruction.

Materials used are predominately those employed on construction for reasons of uniformity and because these materials can generally be stocked readily and cheaply. The use of special aggregates and oils is rare.

V. **Summary**

Routine bituminous maintenance is handled by the regular maintenance organization, the personnel of which is now trained and experienced in all types of ordinary maintenance work. Special maintenance is handled by the regular maintenance organization, by extra gangs or by contract as the case may be, depending upon the extent of the job and other influencing factors. All equipment necessary for routine maintenance work is immediately available in all maintenance districts, and in addition sufficient equipment for quite extensive special maintenance jobs can be made readily available.

Since the various bituminous types of surfacing total an extremely large mileage, distributed more or less evenly over the states, it is obviously most desirable that all features of maintenance of this type of surface be handled in a routine manner by the regular organization. Responsibility for analysis of the trouble and the decision as to the remedy, in the case of regular maintenance, lies directly with the man locally responsible. Special maintenance jobs of this nature demand the general direction of the District or Division Engineer, who may, in turn, secure advice from the headquarters organization and assistance from the laboratory.

Failures of bituminous surfaces are in general from causes which are quite obvious. In the writer's opinion, the only ones which are serious from a standpoint of cost of repair are those due to foundation weaknesses. Surface failures are generally readily repaired and in many cases would not have been experienced had the foundation been more adequate. The desire to secure immediate relief from dust and corrugation has actuated highway users in demanding and securing the oiling of surfaces which were on poorly drained subgrades and which were entirely inadequate from a standpoint of metal and resultant load carrying ability.

Proper maintenance of these surfaces is, of course, expensive and difficult, if not all but impossible, and the routine to be followed depends greatly upon the anticipated reconstruction program; that is, upon how long the road will have to be carried as a makeshift before it is reconstructed to meet modern traffic conditions.

Generally in the Pacific states the bituminous surface, regardless of the type, on new construction is placed upon a full ballasted section. About six inches of ballast is the absolute minimum and this ballast is spread evenly over the entire roadbed prior to the surfacing in order to provide for drainage under the mat and for stability.

Correction of small failures on light bituminous surfaces consists of localized surface patching or of reworking.

Surface patching is accomplished with premixed material, with material mixed at the site of the work, or by the penetration method, whichever type best meets the needs locally. More extensive failures in the case of light mats and surface treatments are generally handled by scarification and replacement, at which time it is often the practice to place an additional thickness of ballast. Armor coating is used for the purpose of securing a non-skid effect and for uniformity of appearances. This work is, except on rather short sections, generally accomplished through contract. Light seal coating is quite local in nature and when done is handled by the maintenance forces.

Observation would lead us to believe that the rapid increase in the number of vehicles, together with greater speeds, has created a condition where arterials carrying an appreciable amount of traffic had to be made free from dust to satisfy public demand, even though in many cases the subgrades were entirely inadequate. This development cannot logically be criticized, as immediate relief was necessary and as in many cases it can be demonstrated that even the excessive maintenance charges do not represent an actual loss when comparisons are made as against the added initial costs of a more durable surface. The increased speed and volume of traffic, however, has created a condition where all maintenance operations create an extreme hazard and subgrades therefore should be created with the objective of a minimum of surface maintenance. Logically, therefore, the objective should be the reconstruction of the weaker sections as rapidly as possible to a standard which will permit a reduction of the routine maintenance to a minimum. In the meantime, there is apt to be a waste of funds involved in local repair of sections which will, of necessity, be reconstructed in their entirety in a short time. Very close coordination should therefore be maintained by the maintenance and construction organizations to the end that possible waste of gas tax funds, due to ill-advised expenditures for haphazard repairs upon sections which must soon be reconstructed in their entirety, can be eliminated.

MAINTENANCE SECTION DISTRICT REPORT

By T. R. Perry, Bituminous Engineer,
Iowa State Highway Commission

Missouri and Iowa comprise this District. All information relative to Missouri has been secured by letter from Maintenance Engineer Rex M. Whitton, and his remarks are quoted verbatim in many places through this paper.

Stabilized base consists of 1,600 to 2,000 cubic yards of gravel or stone mixed with 25 to 30 per cent of soil binder and consolidated by wetting and rolling. Stabilized base extends from shoulder to shoulder. Edge strengthening consists of approximately 600 cubic yards of gravel or stone mixed with 25 to 30 per cent of soil binder and consolidated in a V trench 6 ins. deep at the outside edge and 2 ins. deep 5 ft. toward the center of the road. The width of roadway edge strengthened is 24 feet.

The approximate mileage of the various types of bituminous surfaces in these states can be summarized as follows:

	Miles in each State	
Types—	Missouri	Iowa
Oiled earth standard width	30	None
Oiled earth along 9-foot concrete paving	90	None
Blotter treated earth	95	None
Bituminous and penetration macadam	60	None
Rock asphalt surface	40	None
Retread and similar types	130	None
Asphaltic concrete	50	None
Miscellaneous types	35	None
Bituminous mat	1870	170
Inverted penetration heavy type	None	332
Stabilized base	660	114
Edge strengthened	None	177
Total mileage of all types of bituminous surface in both states	2902	

Bituminous Maintenance Organization

Missouri Missouri is divided into divisions comprising several counties under the supervision of the Division Engineer.

Each division is divided into districts comprising two or three counties under the supervision of the District Foreman.

Iowa Iowa is divided into six districts comprising 16 to 18 counties under the supervision of the District Engineer.

Each district is divided into divisions comprising three to four counties and under the supervision of the Division Maintenance Engineer.

The bituminous maintenance field organization in both states is somewhat similar and can be divided into about two classes:

1. Routine Crews
2. Floating Crews
   - A. Division Crews in Missouri
   - B. State Crews in Iowa.

Neither state has a definite year around bituminous maintenance organization.

Routine Crews

Missouri Routine patch work, shoulder maintenance, minor subgrade repairs, spot sealing and other minor repairs are handled by the patrolman on his particular section of road under the supervision of the District Foreman.

Iowa This work is handled by the state maintenance organization of each county and not by any single patrolman. This organization is under the supervision of the Division Maintenance Engineer.

Shoulder Maintenance

Missouri Shoulder maintenance consists of mainly dragging and rolling the shoulders during the spring months when they are soft and easily rutted by traffic. The shoulders are not treated with bitumen but are maintained as earth shoulders.

Iowa Iowa treats all shoulders at time of construction with a heavy priming and then renews the treatment as needed. It is essential to roll these shoulders during the spring months.

Floating Crews

Missouri During the summer construction season Missouri organizes in the various divisions special floating crews. These crews are under a foreman trained in the particular work handled. These crews are responsible to the Division Maintenance Engineer in the division where the work is being done. These crews remain in the division where they are organized and in the opinion of the Missouri Maintenance Department are more efficient due to the fact that they are more familiar with local conditions than a crew which moves from one division to another. These crews perform all kinds of reconditioning work, resurfacing, surface treatment, etc. The larger reconstruction jobs are contracted and handled by construction forces.

Iowa Iowa has special crews which handle all major bituminous repair work not let by contract. This includes much the same kind of work handled by the Missouri division crews. This crew is under a very capable and experienced foreman. The crew is responsible directly to the Bituminous Engineer. The crew follows a definite regular schedule that is worked up early in the season. This schedule is worked out following a reconnaissance made in the spring with the Division Maintenance Engineer, the District Engineer and the Bituminous Engineer. Changes or adjustments in the schedule are made as occasion demands. The crew is composed of the foreman, distributor operators and tank car heater men. All other help is furnished by the division in which the work is done.

The division organization handles only subgrade failures, requiring frost boil treatment, ditch cleaning and other drainage work. Iowa contracts all contractable items on which an intelligent estimate can be made. These items include all aggregate, bitumen, practically all armor coating and the reconstruction of old mats where complete tearing up and remixing of any considerable amount is required. Bituminous work, both maintenance and construction, is handled by the Iowa Maintenance Department. The Bituminous Engineer is directly in charge of both.

Equipment

The equipment for maintenance of bituminous roads can be divided into about three classes:

1. Patrol Equipment
2. Division Equipment
3. State Equipment

Patrol Equipment

Missouri Equipment assigned to regular patrols is light enough that it can be easily moved around on the patrols and sufficient for a crew of two or three men. Patrolmen are equipped with a dump truck and the necessary small tools. A small pull type roller, and an asphalt kettle for each county or two counties are necessary.

Division Equipment

Missouri Equipment for the special or division crews consists of a distributor, tank car heater, asphalt pump, supply tanks for hauling bitumen, power roller, broom, chat spreader, windrow equalizer, and necessary equipment for mixing, preferably motor graders, also graders and scarifiers for handling subgrade failures.

In planning equipment for special maintenance crews of this type one should not overload a crew with heavy equipment which is difficult to transport from one job to another. Too much heavy equipment runs repair costs up unnecessarily.

Distributors used on repair crews are 400-gallon capacity, mounted on 1½ or 2-ton trucks. Distributors are not used to transport bituminous materials from tank cars to the job unless the haul is very short, all material being hauled in insulated supply tanks. These tanks are loaded at the tank car with an asphalt pump and the material transferred to the distributor on the job. Rollers should not be heavier than five tons and in most cases a three-ton roller is heavy enough. One or two motor graders are usually assigned to a crew. These are supplemented as needed by additional units borrowed from neighboring patrols. A crew thus equipped is easily moved from one job to another.

Patrol Equipment

Iowa In Iowa each county maintenance organization is equipped with small trucks and dump bodies, motor patrols, a 400-gallon power spray unit, or a small spray unit attached to a regular tar or asphalt kettle and small tools. A pull type roller weighing 180 to 200 pounds per lineal inch of width (60 inches wide) is assigned to each bituminous section of road.

Division Equipment

Iowa Each division is equipped with a disc, power sweeper, aggregate spreaders, windrow equalizer and bituminous mixer.

State Equipment

Iowa The state crew is equipped with 400-gallon distributors on Ford or Chevrolet trucks, one-car tank car heater and a Ford or Chevrolet pickup with covered top. All other equipment is furnished by the county or the division in which the work is done.

Both the distributors and the pickup are equipped with hitches to transport the tank car heater. In this way the next car of bitumen is always hot and ready to use when the distributors arrive on the job. No supply or transport tanks are used. All material is hauled in the distributor. This is possible because the maximum haul on any section of road is not over 12 miles from a railroad siding.

General Comments

Missouri Bituminous repair work naturally brings up the question of supply of bituminous materials. It is important that materials be on hand when needed. Missouri has placed 10,000-gallon storage tanks at central locations from which patrolmen can obtain such materials whenever needed. Special crews also stock pile small quantities of mixed materials on each section during the summer. Stock piles of aggregate are also placed on each section. With these materials readily available patrolmen can make minor repairs as needed and not be delayed waiting for material.

Iowa Iowa stocks all bitumen in barrels at railroad locations which are usually near the maintenance garage. Barrels are used because the mileage of bituminous roads is scattered throughout the state and also due to our short haul. Another reason barrels are used is because we are thus not confined to the use of any one particular kind of material. The railroad service is such that the state crews do not have to rely upon storage material.

At the time of construction, material aggregate is stored along the road and then replacements are made as needed. The county organization provides the mixed material as occasion demands. A portable bituminous mixer is used for this work. Mixed material is stored only a sufficient length of time to permit proper areation before being used.

Maintenance Costs

Iowa A comparison of maintenance costs do not mean a thing unless all the individual items making up the total cost are thoroughly understood and uniformly accounted for. Iowa is attempting to keep definite and uniform costs on all bituminous work. Only a start has been made, hence the results are of little value to anyone else at the present time.

The general scheme of cost keeping is divided into

1. Construction Costs
2. Maintenance Costs

1. Accumulated construction cost by years. This cost is broken down into

   a. Base
   b. Surface
   c. Average cost of both per mile of road.

2. All maintenance costs for the bituminous roads in each county are charged directly to Unit No. 4. This

cost is distributed into Maintenance Proper and Betterments. Betterments are in turn broken down into

a. Base (Major repairs or new work)
b. Surface (Major repairs or armor coating)
c. Equipment (New or used charged to each county).

To illustrate maintenance costs let's take the 1935 costs in Fayette county with 13.3 miles of 1½-inch mat, 22 feet wide, built in 1932. During 1935 this road was armor coated, costing by contract $11,795, and improved with $1,430 of frost boil work. New equipment purchased and assigned to this county amounts to $1,989.

The total bituminous maintenance charges against Fayette county, average per mile		$1,491.00
Betterments, average per mile		1,144.00
a. Base (additional frost boil work)	$ 107.00	
b. Surface (armor coating)	887.00	
c. Equipment (new)	150.00	
	$1,144.00	
Maintenance proper equals $1,491 minus $1,144, or average per mile		$347.00

Maintenance proper includes all minor expenses to the surface, roadbed and structures except the above major items and snow removal.

Missouri The maintenance costs in Missouri are kept in the following manner:

General Patrol
Surface ....$
Roadbed ....
Structures ....
R/W Maintenance .... —— $——

Repairs and Replacements
Surface ....$
Roadbed ....
Structures .... —— $——

Additions and Betterments
Surface ....$
Roadbed ....
Structures ....
R/W Maintenance .... —— $——

Special Work
H/W Conv. and Safety........$
Erection of S. Shed..............
Snow Removal ....
Assisting Traffic ....
Traffic C. and Census............
Indirect Time ....
Flood C. and Prevention...... —— $——
Total for Section $——
Average Cost Per Mile $——

Failures

Iowa The subject of failures on bituminous roads is of keen interest to all persons attending this conference. In fact, failures occupy such an important position that complete coverage can not be adequately given in this paper. To each maintenance department falls the duty of solving the failures which have occurred in the past construction. Only in this way can new construction be made adequate to stand up under traffic. Here in Iowa we are satisfied that our major failures are due to poor subgrade. The mats are reasonably sound so far as the kind of aggregate used, aggregate grading, amount of bitumen, manipulation and consolidation are concerned. We are now constructing bituminous surfaces only on those roads that have been properly graded, and a subgrade provided which we believe will stand up.

Next to subgrade failure is failure due to moisture entering the mat and subgrade from the top. Capillary attraction has been accused too many times of being the direct cause of the failure. Armor coating and seal coating are necessary to stop the penetration of surface moisture.

Moisture in a mat can be handled successfully only by tearing up the infected sections, remixing and relaying.

In Iowa we strongly believe that if the base is sound and adequate, the thickness of the mat is of little importance. On the other hand, if the base is not adequate, then failures will occur regardless of any thickness of mat that can be economically constructed.

Missouri Failures in bituminous surfaces in Missouri are similar to those in Iowa. Nearly all of our failures can be traced directly to poor subgrade support and poor drainage. Very few failures can be traced to bitumen and aggregate used in the surface.

General Comments

Failures in this district might well be classified as follows:

A. Surface failures
  1. Raveling
    a. Lean mixture
    b. Moisture in aggregate
    c. Dead or oxidized bitumen
  2. Corrugating
    a. Moisture between mat and subgrade or in the mat proper
    b. Excess bitumen in mat
  3. Cracking which permits surface water to enter the mat and subgrade.

B. Subgrade failures
  1. Low load carrying ability of the soil when mixed with water
  2. Frost boils
  3. Sand pockets, peat and other unstable soil not dependent on moisture
  4. Poor drainage.

These failures have been corrected in the following manner:

A. Surface failures
  1. Raveling
    a. Remix and add required bitumen. In some cases only seal or armor coating required.

    - b. Tear up and dry.
    - c. Same as "a." In other cases 4 to 6 feet of mat along the edge has been remixed with added bitumen, relayed and the entire surface armor coated.

2. Corrugating
    - a. Tear up and dry out.
    - b. Add additional aggregate. Generally the aggregate should be added and mixed with the mat. Some success has been secured by adding crushed stone and rolling into the mat.

3. Cracking
    - a. Strengthen subgrade, sometimes seal or armor coating will give relief.

B. Subgrade failures

1. Change the characteristics of the soil by stabilizing method.
2. Give special frost boil treatment.
3. Replace or bridge over.
4. Provide proper drainage.

MAINTENANCE OF BITUMINOUS HIGHWAYS IN SOUTH DAKOTA

By W. N. Lovejoy, Construction Engineer,
J. F. Jacobs, Maintenance Engineer,
South Dakota State Highway Commission

The South Dakota Highway Commission started the construction of bituminous surfaced highways by contract and with federal funds in the spring of 1931. As is usually the case with new ventures, advisors were called in to tell us the best ways to build these low cost roads. The reason for mentioning this to begin with is that some of our worst maintenance problems were an outgrowth of that advice. The most disastrous advice was the following: Any gravel surface road that has successfully carried the traffic is suitable for a base course on which to construct a bituminous mat. We have approximately a hundred miles of this sort of construction which is a constant source of trouble. The principal cause is the lack of base thickness and poor sub-drainage which never showed its true nature until a tight bituminous cover was placed thereon. A few more sources of maintenance trouble were the use of an overabundance of road oil in the mix, the lack of a sufficient quantity of filler in the mix, and it is remembered too that one advisor told us that when a lack of adequate filler confronted us, the proper thing to do was to increase the percentage of road oil and use a higher viscosity material. This fallacy was easily recognized the first time it was tried out.

Not all of the advice was bad, however. Much it it was of value and is still being heeded—insist on good quality bitumens; avoid the so-called "cracked" material for mat binder; dry the aggregate thoroughly before mixing bitumen into it as moisture is the worst enemy to the stability of the mat; avoid aggregates having high shrinkage properties. Lean mixes are more stable than rich mixes and it is easier to cure raveling than it is to correct corrugating—not that we haven't had some of the latter, but we have kept it to a minimum. It is much easier to put heavy penetration seal courses on lean mats than it is to scarify and add more aggregate to overlay rich mixes, and too, it has always seemed to us that rich mixtures invite moisture trouble by suction from below and then "old demon" emulsification gets to work on the mat and only a complete reworking will correct the bad situation.

At this point it might be well to give a statement of how much bituminous type highway mileage South Dakota has, and I will endeavor to make this resume as accurate as possible.

	Miles
During and prior to the year 1931 there was constructed	154.051
During the year 1932 there was constructed	156.174
During the year 1933 there was constructed	90.088
During the year 1934 there was constructed	139.004
During the year 1935 there was constructed	109.449
During the year 1936 there is under construction and will probably be completed	186.817
Total	835.583

Besides this, the Bureau of Public Roads is building this year in the National Forests of South Dakota a total of 23.356 miles. The Park Service has constructed in Wind Cave National Park 7.000 miles. Making a grand total of 865.939 miles.

Note: This total does not include 100 miles of light surface treatment work which is being undertaken late this season as a dust palliative, which will probably be followed next year with a substantial mat.

This work can be classified by type as follows into five groups:

(1) Plant mix graded aggregate type, 3″ mat thickness with slow curing and medium curing liquid asphalts, 145.7 miles; average cost approximately $6,000 per mile.

(2) Road mix graded aggregate type, 3″+ mat thickness with slow curing and medium curing liquid asphalts, 507.2 miles; average cost approximately $5,200 per mile.

(3) Road mix graded aggregate type, 1″+ mat thickness with slow curing and medium curing liquid asphalt, 92.1 miles; average cost approximately $3,300 per mile.

(4) Retread macadam aggregate type with rapid curing liquid asphalt, 2″+ mat, 76.7 miles; average cost approximately $5,500 per mile.

(5) Retread macadam aggregate type with medium viscosity refined coal tar, 2″+ mat thickness, 44.2 miles; average cost $5,425 per mile.

Summing up the five groups, we have a total of 865.9 miles which is located in 45 of the 64 counties of the state. The average construction cost per mile of all types has been approximately $4,000 per mile. Unfortunately, this mileage is badly scattered over the state on account of the laws and policies governing apportionment of highway funds. Public sentiment is crystallizing into a determination to get at least one dustless highway across the state east and west within the near future, a distance of approximately 440 miles. This will have to be accomplished in order to keep and regain tourist travel in the state.

General highway maintenance in South Dakota is handled in that rather unsatisfactory manner of having the separate county highway organizations do the work and then receive reimbursement from state highway funds. Our legislatures during the last sixteen years have been very "county-minded," giving 80 per cent of our funds from vehicle license taxes directly to the counties, and the worst misfortune was the necessity of using half of our 4-cent gasoline tax to retire state bonds in no way connected with highways. This all tends to hamper our getting a centralized maintenance department, but we have made a determined effort from the start to keep bituminous maintenance within the State Highway Department and not let each county dabble in it.

The state is divided into five highway districts and each district engineer is responsible for the maintenance of the state highways in his district. During the last two years we have set up full time bituminous maintenance crews in each district, equipping them with kettles (and of course trucks), etc., having power-driven, hand-operated spray jets and short-length spray bars. These units vary in size from 160 gallons to 600 gallons. These crews do all the necessary repair work, from scarifying to sealing, and we now believe that it is much better to be on the job continuously with small units than to wait for a big outfit to move in when major difficulties have arisen. Our earlier decision was to have one large maintenance outfit somewhat similar to a contractor's organization and make the "rounds" from project to project as occasion required and convenience permitted. We found this to be a rather unsatisfactory and cumbersome arrangement and are now using the large outfit only for construction and reconstruction work on the early constructed projects.

No definite number of miles can be assigned to a maintenance outfit; the necessities of the work must govern. Some projects require very little maintenance and others are forever needing attention. Probably an average of 60 miles will be found to be about the proper length to assign to an outfit.

At present we are operating ten small outfits on a more or less full time schedule. Each outfit has a personnel of approximately five men, and their equipment consists of a 1½ to 2-ton truck, a kettle, small tools, a home-made roller, and power patrol with scarifier.

Winter maintenance is also carried on to a large extent. Fortunately, bituminous mats do not need so much attention in the winter season. Freezing may cause bulges and heaving in a few instances, but for the most part there is an added stability present during the winter months. However, with the coming of spring, wet snow and the departure of frost from the ground, the worst conditions of the year must be met. During the winter season, provided there isn't too much snow, the contraction cracks are filled with bituminous material and dried warm sand. A determined effort is made to keep melting snow off the mat. Nothing soaks up the edges and shoulders more disastrously than snow allowed to melt on the edges of the road.

At the risk of being somewhat trite, I will describe the performance of what is probably the most common maintenance work, namely, repairing the breaks in the edges of the mat. Repairs to the outer third of the mat occasions more work than all the rest of the road by far. Where traffic has broken down the shoulder support and a definite breakup and sag has occurred, the men dig out the failed area, using care to pile separately the failed bituminous treated aggregate so it can be salvaged and taken to a stock pile and eventually worked into scarified areas. The area is laid out as nearly rectangular as possible and the edges are cut vertical and not just any old way, and the excavating is carried down far enough to get to a solid support. All the soft excavated material which failed to "stand up" is removed and wasted. The hole is next filled with oversize gravel to within about two or three inches of the top and thoroughly tamped. There is also a lead out "French" drain put in to insure against a recurrence of the trapped moisture which is the usual cause of the failure. The tamped backfill and edges are next painted lightly with bituminous material, usually with RC-1, and the stock-piled material of the same nature as the mat is then filled into the top portion of the hole in layers slightly overfilling it and is then tamped into place, after which it is again opened to traffic. We have been experimenting recently with the idea of placing permanent lumber edge forms for repairing weak shoulder areas and we believe it will be worth while. Far too many maintenance men treat the bituminous stock pile material, which costs about $3.75 per c. y., in much the same manner as patch gravel on gravel surfacing. The difficulty seems to be to educate these men to differentiate between a patch and a repair. After the repaired area has been under traffic for a week or more it is again examined for defects and then sealed with RC-1 and screened sand, and should be just as good as the rest of the mat.

Our stock piles are made up at the same time the project is constructed. Gravel and filler are mixed and dried on a side road with motor patrols, and road oil, usually SC-5, is mixed into the aggregate windrow in a slightly higher percentage than used in the mat. The mix is placed in a compact, well shaped pile in a high and dry location. It has been customary to estimate the stock pile needs at the rate of 35 cubic yards per mile of project, but there seems to be no correct ratio, either it is entirely too much or not enough.

This season we have been using quite a good deal of MC-3 in road mix and MC-4 in plant mix, and I have been rather doubtful about putting up any very large stock piles for fear they would harden in a year or so.

Last year we listened to a speaker at this meeting tell us about a soil he called adobe and the difficulties encountered in maintaining a bituminous mat on top of it. I believe we have a soil covering most of the western half of South Dakota which is fully as bad but we call it gumbo. It is distintegrated shale, which is an A-6 to A-7 soil, and it is a very plastic and unstable material when wet and cracks badly when dry. It also has cumulative properties toward water and never lets it go, and the cut sections are usually worse than the fill sections with this type of soil. We haven't effected any definite cure for our maintenance troubles in gumbo, but we have alleviated them somewhat by thickening the edges of the mat and putting in "French" drains at every soft place in the shoulder and then rolling the edges at regular intervals with a heavy pull roller. New work is being put down with a thicker base course. Mats laid on gumbo seem to lose their life in about three years, and last fall and this summer we have been reworking some of the oil surface mats laid in 1931 and 1932. We have had to add almost as much road oil as we put in originally. This reworking of 1,000 cubic yards per mile mats has cost us about $1,800 per mile and we are making the experiment of putting in a layer of coarser rock and road oil as a sort of base course lift, hoping that we can break up the emulsification action which gumbo seems to cause.

In the eastern part of South Dakota where the soil is more granular we have had much better success with oil mix mats, and except for a few spots where ground water hasn't been properly handled, maintenance has not been excessive in cost.

This year we have let by contract about a hundred miles of seal coat work on several projects that have been down three years or more. The cost has been approximately $290 per mile, including 2,500 gallons of RC-1 and 25 cubic yards of screened sand. This has been a fully satisfactory procedure and will probably be continued.

Maintenance is not an easy thing to describe and outline. There is always something different developing and eternal vigilance is the best plan of action.

It is realized that traffic census and soil surveys are a great help both in designing a project and forecasting maintenance costs. At present we do not have either, but it is hoped and expected that the State-wide Highway Planning Survey now in progress will furnish us both of these at some future date.

An analysis of maintenance costs in South Dakota will be made in conclusion. We have figures compiled only for the years 1933, 1934, and 1935. The total maintenance cost per mile per year for 1933 was $166.82; for 1934, $264.49; and for 1935, $282.36; an average for the three-year period was $246.78 per mile per year, which it is believed will be close to the 1936 figure. Several expensive reseals and retreatments were paid for in 1934 and 1935 out of maintenance funds which should really be counted as construction. These amounts given include all the yearly charges against the project and are not alone bituminous surface repairs.

It might be well to give a statement as to just how the different types fared in maintenance cost per mile per year over the three-year period.

Type 1—Plant mix graded aggregate type, 3″+ mat, $131.07 per mile per year.

Type 2—Road mix graded aggregate type, 3″+ mat, $212.27 per mile per year.

Type 3—Road mix graded aggregate type, 1″+ mat, $222.46 per mile per year.

Type 4—Retread macadam aggregate type (rapid curing cut-back asphalt), 2″+ mat, $456.73 per mile per year.

Type 5—Retread macadam aggregate type (medium tar), 2″+ mat, $546.53 per mile per year.

The predominating advantage in favor of the plant mix type is due in part to merit and in part to good luck with the comparatively small mileage. The predominating disadvantage at which the two macadam aggregate types appear is due in large part to the heavy traffic they are subjected to and the expensive retreatments which were charged against maintenance. It is believed another year will see a more equitable adjustment. Types 2 and 3 show more truly the average cost of yearly maintenance as they include nearly 600 miles out of the 866 miles total mileage, or approximately 70 per cent.

A breakdown of the 1934 figure of $264.49 cost per mile per year maintenance cost shows $47.75 charged to a miscellany of items, including cleaning ditches, removing snow, etc., all of which is chargeable to any type surface. The strictly bituminous items are $183.73 regular repairing surface and $33.01 to stock piles. A breakdown of the 1935 figure of $282.36 cost per mile per year maintenance cost shows $86.40 charged to a miscellany of items including cleaning ditches, removing snow, etc. The strictly bituminous items are $174.39 repairing surface and $21.57 for stock piles. The bituminous maintenance in 1935 really shows a decrease over 1934, and with a better understanding gained by experience we trust will enable us to improve the record as we go along.

SUMMARY OF PAPERS ON "MAINTENANCE OF BITUMINOUS SURFACES"

By H. G. Nevitt, Manager, Road Oil and Asphalt Division,
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In the previous Montana Conference, and in fact nearly all other meetings hitherto, the attitude has been that maintenance merely duplicates the utilization of fundamental principles and methods used in the construction of bituminous mats. Consideration showing this promise to be unsound, the maintenance section of this conference was formed. The policy of the section has therefore been primarily to review and rationally analyze the present maintenance situation. Through this we hope to bring out its major problems for discussion, and lay the groundwork for concentration upon improvements in maintenance practices in later conferences.

Organization of Section

Preliminary analysis indicated that about 21 states would comprise the area from which the Conference would attract attendance, reports from which would give a very representative survey of maintenance practices. This territory, divided into seven districts, was assigned to men primarily selected for their known specialized interest and experience in bituminous problems, with less attention given to their official connection or responsibility for actual maintenance work. In fact it was felt that in this preliminary survey of bituminous maintenance it would be a distinct advantage to have the viewpoints of men drawn from all the various departments whose work ultimately affects maintenance, rather than maintenance officials only.

In order to coordinate the work in the seven districts, the Chairman worked up a possible outline of the field to be covered by the individual papers. This was merely a suggestion, with the thought that a uniform trend in the papers would aid their summarization and discussion; the various contributors were in no way restricted to this outline or the viewpoint it might infer. As in all pioneering, mischances and oversights occurred to prevent results exactly as planned, so that not all the ultimate contributors were given the complete picture or all states properly represented, but in general the papers follow the outline planned and give an excellent cross-section of maintenance practices in the western United States.

Too much cannot be said of the excellence of many of the papers. They cover so much territory that they unquestionably present a representative picture. The detailed comment on organization and equipment, the complete tables of costs and so on in many of them, offer a wealth of information which cannot be brought out either by the Chairman or the discussion, but to which all those concerned with maintenance are referred for detailed review and consideration. The Chairman's effort will be to briefly review the general field covered, and bring out the major points of disagreement in practice, with principal attention to the engineering phases of failures and their remedies as the apparent greatest field for discussion by the Conference.

Handling of the Subject

Discussion of bituminous maintenance falls into two general classes. Administration, covering such points as personnel, equipment, procedure and statistics, is evidently to a large extent a local problem, determined by specific controlling factors. It consequently seemed desirable to summarize the situation on these points in the districts, and for the Chairman to briefly point out general trends and conclusions without expecting much discussion of them, since the local factors would decide the proper policies on such matters for each state. On the other hand, engineering policies and opinions as to failures, their causes and remedies, would seem of universal application and discussion, though a much less tangible subject, one more difficult for both the writers of the papers to cover and the Chairman to summarize. The summary and the discussion will be carried out along these two lines, following the outline given in the appendix.

A summary of the existing mileages of bituminous types, Table 1, shows that bituminous surfaces have definitely emerged from the experimental classification. In fact they represent a tremendous investment and upkeep charge, as well as the largest mileage of any type surface in the country.

Maintenance Organizations

Consideration of the detailed description and discussions of maintenance organization shows certain agreements and trends. Agreed conclusions seem to be: (1) that the routine organization must have the proper training and equipment for its duties, with only bituminous surfaces under its care; and (2) that special (large job) maintenance must be decentralized and kept to as small and localized units as possible, though with flexibility in the shifting of the forces and equipment around as needed.

Beyond these points of agreement there seem to be two schools of thought, though not too clearly defined. One group leans toward what is essentially the patrol system for routine maintenance. The patrol generally consists of one man with a helper, equipped with a kettle and other light tools, handling all routine maintenance on about a 30-mile section. All work beyond the province of this small force and light equipment is then handled by a district crew more fully organized and equipped. The other school expands the patrol groups into a crew organization covering a longer territory (within about a 50-mile radius) combining the functions of the patrol and the special maintenance crew. In all cases the special maintenance or major repairs may be helped out by the central state organization, or by contracting the work. The merits of the patrol versus the small fully equipped crew may warrant some discussion by the Conference.

Equipment

Naturally the equipment set up is determined by the organization. It is evident from the papers that equipment is being given careful study and definite ideas on the subject have been developed. No definite trends, other than the necessity for efficiently equipping trained men, competent in this specialized field, for the job, appear in the discussions. Attention is called to the tendency to develop special equipment designed specifically for maintenance needs, such as the Montana plant mix patching plant.

General Maintenance Policies

Not many maintenance policies seem formulated as such, although the papers indicate that definite opinions are crystallizing on many phases of maintenance. The maintenance organizations in the states represented are evidently very well knit organizations with close cooperation from the top down, so that the majority of problems involved in bituminous repairs are well known to all concerned. As a result, decisions as to repairs seem to be arrived at without any formal system of handling. In general the patrolmen decide on the proper steps for minor repairs, the oiling crew foreman, district engineer, or state maintenance

TABLE I

Reported State Mileages of Bituminous Surface

State	Heavy Mats	Light Mats	Stabilization Treatments	Temporary Treatments	Total Reported
Idaho	1708	......	46	......	2425
Montana	1245	780	1033	......	3067
Wyoming	1575	685	165	......	1754
South Dakota	653	213	......	100	966
Nebraska	364	592	17	......	868
Kansas	47	527	......	......	2848
Iowa	......	509	114	......	623
Missouri	220	1965	......	215	2400
Oklahoma	......	1337	......	......	1337
New Mexico	......	......	......	......	993

Average total per reporting state—1728.

Description of Classifications

Heavy Mats—All gravel, stone or sand mats 2¾ inches or over.

Light Mats—All gravel, stone or sand mats ¾ to 2½ inches.

Stabilized Treatments—All bituminous base stabilization treatments, either of gravel or soil with or without a top armor coat or mat.

Temporary Treatments—All dust laying, oiling surface, earth oiling, or penetration types of a temporary nature, including mats under ¾ inches.

NOTE: Classification by some writers does not follow this system, and the figures given may not correctly divide the mileage according to it. In some cases this mileage is up to the 1936 season, in others it includes 1936 jobs.

engineer ultimately deciding the more serious questions, with apparent general agreement throughout as to how far the responsibility should be carried up in each case. Decision as to when the materials department should be called for consultation is similarly a matter of individual opinion in each case, as is also the decision between work to be done by the patrols and by the general district crews.

The papers check personal observation by the Chairman that the highway maintenance departments in the western states, with their very flexible organizations, lack of red tape, and surprisingly close touch of the maintenance engineer and his district assistant with problems over such wide areas, are showing great efficiency in the majority of cases. Yet the possibility appears that bituminous maintenance might be improved, without losing these advantages, by a somewhat more definite handling of repairs, and routing the information reports on them through definite channels, including the materials organization. In making this statement the engineering phase of such repairs, particularly the systematic classification of the type of failure causing them, later discussed, is also an important and perhaps the leading reason. This subject may merit some conference discussion.

That indirectly some maintenance policies are appearing is evident from the papers. Mr. Lovejoy's remark about the necessity of distinguishing between a patch and a repair is typical of this. Repairs, even of the routine type and resulting from traffic usage rather than true failure, are receiving systematic treatment. Particularly has the necessity for specialized shoulder maintenance become realized in contrast to rather haphazard policies once observed of letting shoulder failures go, except for casual attempts at patching with stockpile material, until the whole section required reworking.

Binder Supply

One policy upon which agreement as to principle but difference as to method has developed, is an available supply of maintenance binder. All agree that the proper bituminous materials for repairs should be stocked and available at all times at convenient locations. The disagreement is as to method. One school relies upon drum storage, with its benefits of wide distribution and stocking of varied types of material. The other depends upon carload tank storage, more widely scattered unless there is a considerable bituminous mileage, and the restriction of binders to one or two specifications. The latter offers economies due to cheaper handling costs, and apparently a field for development of a bituminous material of almost universal maintenance use.

Winter Maintenance

The Chairman finds personal pleasure in the reference to winter maintenance in the papers. It has long appeared that insufficient work was being done in this season. Surface treatments, particularly sealing, can be done in quite cold weather if the road surface is superficially dry and the bituminous binder adapted in type to the conditions. Even where the permanent repair indicated by the trouble cannot be made, temporary winter measures such as sealing or patching may pay by preventing further loss in the spring breakup while waiting for suitable weather for the final correction. Further consideration of winter repair work and binders suitable for it is suggested.

Maintenance Costs

The maintenance statistics presented by a number of the papers bring together for the first time extremely valuable data. Time does not permit real discussion of the information and conclusions from it by either the Chairman or the Conference: all interested are referred to the individual papers for careful study of the figures. An attempt will be made to touch upon a few high points.

The costs reported show a rather marked uniformity considering the differences in conditions, types, original costs, accounting methods, and so on, between the reporting states. The real difference between the costs seems to lie in the distinction between true maintenance and betterment. If the type constructed, even though possessing serious faults, can be made to stand up without reconstruction or excessive special repairs, it will show typical true maintenance costs. As has often been pointed out, even this is ultimately a betterment operation. Every time the road is sealed, every time a weak subgrade or shoulder spot is strengthened, the ability of the road to carry traffic more efficiently is improved, until in ability to perform service it has reached a higher type. On the other hand, types which cannot be maintained, or economically so, as constructed, and are continually being appreciably thickened by so-called maintenance, should be classified as betterment.

With the distinction in mind, it appears that types requiring only maintenance can be maintained at a yearly cost for all items of from $200 to $250 per year. At such cost the surface appreciates in utility and value, rather than depreciates as is the case with rigid pavements: further this maintenance cost shows a tendency to decline with time. If the original mat was so thin or improperly suited to the conditions and betterment maintenance is required until the type has been corrected, this annual figure in this period will be increased by from $50 to $150 per year. If the type is purely a stop-gap or temporary treatment pending reconstruction, the maintenance costs in the interim period vary over the above range, depending on what is done, but these treatments should hardly be classed with permanent construction.

Due to differences in accounting, lack of sufficiently complete reports from all but a few states, and the general complexity of this subject unless simplified by a preliminary analysis, it is the Chairman's opinion that detailed discussion of maintenance costs, at least from a comparative viewpoint between states, is not feasible for this year's Conference except perhaps in a general way. All interested in maintenance are referred to the tabulations and discussion in the individual papers, such as the very thorough analysis by Professor Duff. It is hoped that with these outlining the way, by another year we can have a thorough presentation of this subject, with at the same time many of the differences in cost accounting methods followed cleared up.

Effect of Traffic

Traffic statistics in connection with costs appear even more difficult to obtain. The present highway planning survey may remedy this situation in another year. Meanwhile we have excellent figures from the standpoint from Kansas and Nebraska along with comments from Professor Duff. Possibly the Conference will wish to discuss the opposing views covered by his comment, as to whether or not increased traffic results in increased maintenance costs, provided that the amount and type of traffic never exceeds the capacity of the surface built.

Cost Data Requirements

While throwing some light on the subject, the construction and maintenance cost figures are not yet sufficiently complete to indicate the most economical type of construction to follow, or the best thickness of mat to build for given average conditions. Very evidently, totally insufficient bases or mats are not economical. The resulting attention to eliminating them has tended to obscure differences, from the statistical cost standpoint at least, between the various types admitted to be usable, and particularly between those requiring true maintenance only and those requiring betterment types of maintenance. It is hoped that as the old insufficient bases or mats are eliminated and more and better cost data obtained, information along this line will appear.

Types of Maintenance Work Done

Certain general trends in statistics in connection with the types of maintenance work found necessary are of interest. In spite of the universal complaint about the difficulties of maintaining the earlier jobs, usually those built on unsatisfactory bases, the actual proportion of the bituminous mileage reworked or reconstructed each year is quite small, around 5 to 10 per cent In view of the statement from one state official some years back that their surfacing became obsolescent in eleven years, or required a 9 per cent average replacement of the old surface, this does not appear an unsatisfactory situation. The figures certainly contradict the picture sometimes painted by critics of bituminous construction, that the resulting surface must be rebuilt every few years, and is a total loss in a relatively short period. The figures show the actual situation is that they, on the average, improve with age.

On the other hand the papers indicate that a large mileage, while not requiring serious attention, must be given other than minor patrol maintenance, that is, must be looked after by the special maintenance crews, 60 per cent being a typical figure. The great bulk of such maintenance appears to be seal coating, or an equivalent treatment resulting in a mat thickness increase up to the point of another stage of construction in states starting out with very light mats. The proportion of sealing may soon start showing a decided decrease due to the adoption of sealing as part of construction. Nevertheless, later resealing as the need appears will continue to be an important maintenance operation. It is the Chairman's observation that sealing, being a small portion of the construction job, has never received the attention its usage in the aggregate over the country merits, and that this subject warrants considerable discussion by the Conference.

Failures From Engineering Standpoint

While maintenance organization and policies have occupied a great deal of space in both the papers and the Chairman's summary, and present a number of important topics for discussion, it still appears that the most important phase of maintenance today for the attention of the Conference is the subject of failures from the engineering standpoint. Despite the effort to rationally analyze and outline the subject, it is not as tangible a one as we should like, appearing to offer considerable difficulty in separating and analyzing the effect of each of the variables present. If the Conference does no more than analyze, classify, and clearly separate the various factors affecting failures it will have done a great service. Furthermore, it is the Chairman's opinion that such classification should be the first and most important part of the discussion. Nothing will more clearly indicate the proper solution for each problem, and bring about agreement in opinion on it, than careful distinction between the conflicting factors involved. It is believed that the radically different opinions between states on both construction and maintenance problems are often not so much a matter of differing local conditions as they are different weighting or evalutation of almost the same fundamental factors in the situation.

Emphasis on Bases

The most noticeable feature of the discussion of failures is the complaint about insufficient bases and the emphasis on the need for a proper base—one that will stand up under the actual condition of use after the bituminous surface, with its evaporation controlling characteristics, has been constructed. There is no disagreement as to the need of an adequate base, with preferably a factor of safety for the estimated conditions. The top can be added to or modified with ease and relative economy: the base must be suitable, or the whole job will require rebuilding. It is obviously better to assure its supporting power at the start.

With the benefit of experience, better understanding of the factors involved and preliminary analysis, the feelings of the maintenance engineer about adequate bases can be readily understood. Too often has he been confronted with a job whose base, though adequate in the day of gravel, and for its traffic, has at certain periods of the year, due to moisture conditions under the impervious mat, shown a very small actual distributed bearing power—say five pounds per square inch. Instead of the six-inch mat (or an intermediate load distributing foundation course) required for such a condition, he has had a 1½-inch mat. As time goes by he has reworked it, dried out the base, primed the base, sealed the top, or perhaps even added another stage, all to no avail. No wonder he feels that nothing can be done to make a road stand up that does not have sufficient base.

Nevertheless a word of caution seems in place here. The great difference in maintenance costs on jobs such as the above overshadow the benefits from careful maintenance practices on surfaces with bases that are suitable or high enough in bearing power to be compensated for. If for example the base as constructed will never show less than 25 pounds per square inch bearing power, indicating a three-inch mat is needed, it might be very injudicious to rework the job and strengthen the base because the various measures taken to make a 2-inch or 2½-inch mat stand up had failed. It would seem cheaper to bring up the thickness to the required three inches, provided careful study has resulted in conviction as to the source of the trouble and the means required to cure it. In brief, it is urged that the base problem not be allowed to too greatly distort the importance of other causes of failure or means of correction.

Analysis of Failures

The first step in the engineering discussion of failures and methods used to overcome them is the proper analysis of the cause (or causes) behind each one. Full recognition of the various causative agencies has been appearing in recent years. Today from certain standpoints there is fairly good agreement on the major types of failures, and their cure. Insufficient bases are universally blamed for the majority of troubles, with almost universal demand for reconstruction or improvement of the base as the repair means. Water is another destructive agent blamed by all for many difficulties, with its removal, by reworking, the cure. Finally raveling and similar troubles are the remaining sources of difficulties, with seal coating or further increase in the mat's thickness the usual cure.

While first hand reading of the various papers may indicate such general agreement on the major points, a careful review and analysis of the various discussions does not confirm the impression that the analysis of failures, their cause and cures, are on a strictly rational basis. The time for this summary does not permit detailed discussion of the pros and cons. There are not enough papers which go into failures in detail to point out general trends, and the best that can be done is to attempt to outline the general situation, pointing out the major features that seem to require discussion. It appears that the Conference will have accomplished a great deal if the analysis and classification of failures according to a logical, rational and clear-cut plan results from the discussion.

Structural Elements of Road

It seems evident to the Chairman that the usual bituminous road consists of three distinct elements. The first is the natural subgrade, which has certain definite characteristics under the prevailing conditions in use. Placed on this subgrade is usually another layer of definitely different characteristics. This layer, which is the foundation course, may be gravel or may be the original subgrade material modified by treatment or admixture, but in any event it is a different element in the construction, with different properties. The subgrade and the foundation course together make up the base. Consequently a discussion of failures as due to the base is unsatisfactory in that it does not distinguish between improper action of the true subgrade, such as due to poor drainage, and failure of the foundation course, such as from insufficient thickness. Above the foundation course is the mat, which is of course entirely different from either of the other two elements. It seems absolutely essential that a logical analysis of failures and their cures should start with classification according to the element in which the cause of the failure belongs.

Failure of Structure as Whole

With these three elements decided upon as composing the mat, it should be possible to classify the causes of failure affecting or occurring in each element. However, before such discussion of failures in the different elements, it seems necessary to consider the possibility of troubles that result from failure of the structure as a whole, that is, due to the combined interrelation of the elements rather than any one. The primary function of the road is to resist the transmitted stresses; in other words, carry the load. Such stresses are both distributed and transmitted by the mat course to the foundation, and by the foundation to the true subgrade. The conclusion seems inescapable that, strictly speaking, each one of the elements of the road structure functions in this load carrying action, and it is not logical to arbitrarily assign a failure in ability to carry the load to any one of the three, unless it is definitely due to a condition in that element different from the original design conditions. For example, if a road designed in accordance with an assumed subgrade bearing power fails in a poorly drained spot because the excess moisture present prevented the full development of subgrade resistance, the blame could correctly be placed on the subgrade and corrected by drainage. If, however, a road fails in a properly drained area with normal mat and foundation thickness, the fault can not be put on any one of the three elements. Either the subgrade did not have the assumed bearing power, the foundation did not distribute the load and diminish the intensity of stresses to the expected degree, or the mat did not function in the way intended. If the mat is given no credit for distributing load, the failure might be ascribed to the foundation course, since the subgrade, unless changed, obviously has only its inherent bearing power. If, however, a slightly greater thickness of mat, instead of changing the foundation course or special drainage provisions, would prevent the failure, the trouble might be credited to the surface. It becomes evident that if insistance is made on blaming one of the elements for the trouble, the element to be blamed is set by the cure decided upon. This does not seem logical, and it would appear that such failures should be blamed upon the failure of the structure as a whole to carry the load, with the proper cure set by circumstances. That it will be in almost all cases an increased thickening of the foundation course somewhere or other, does not make the original failure any more logically a foundation failure than it would be a mat failure if the much less usual cure of thickening the mat was indicated.

In this connection there is much opinion expressed that the mat has no bearing strength whatever. Actual experiments on slabs of bituminous mix absolutely contradict this opinion. The entire trouble is that engineers who build 8 and 10-inch concrete slabs for distributing loads take the position that bituminous treatments have no load distributing ability because thin mats of 1½ to 3-inch thickness do not do the same work as the heavy concrete structures. Load distributing ability is entirely relative, and for their thickness bituminous mats have remarkable beam strength. Since the strength of any beam varies as the square of the depth, it is unreasonable to expect much beam action from relatively thin bituminous treatments. Yet, on the other hand, there are many cases where the slight increase in such action due to thickening the mat may be the solution of the problem of weakness of the structure as a whole.

Failures in Specific Elements of Structure

Turning to failures of the specific elements of the structure, the true subgrade evidently is liable to failure from only two usual sources. One is the presence of moisture different from that contemplated by the design, due generally to poor drainage which reduces the subgrade bearing power below the expected amount. Also note the interesting contrary action reported by Professor Duff of such failures from too little moisture. The other source is the presence of pockets of undesirable material, causing frost boils or similar, which were not anticipated in the normal design, which cannot be compensated for by increased thickness in the foundation course or similar.

Failures in the foundation course (except to contribute to the structure as a whole sufficient strength to prevent failure) are rather rare. As commented in the Chairman's original outline, uncompacted sections are about the only sources of such failures, and one of the papers reports troubles of this type. Another type of failure mentioned in the same paper is slippage, failure between the mat and the foundation, which might properly be classed as a foundation failure due to either improper priming of the foundation or lack of sufficient frictional material in contact with the mat.

The remaining element, the mat, is the source of the great majority of maintenance troubles other than the outstanding one of insufficient strength in the structure as a whole. The mat, being a more complex unit, can be expected to offer more types of grief. Also, due to its performing the two functions of doing its share of the load distribution and protecting the other elements of the structure from concentrated surface forces and surface moisture, it would be expected to show more sources of trouble. There seems to be fair agreement in classifying these. We have mat failures due to lean mixtures resulting in either raveling, cracking or water infiltration. Oxidation or loss of life by the bitumen generally results in the same troubles. Troubles due to water result in corrugating, cracking, bleeding, and similar difficulties; also failures due to rich mixtures, which are rare with liquid products and must be distinguished from failures due to moisture—a distinction which is becoming apparent, but does not seem clear cut in all cases. Finally there are mat failures due to other causes, all of which are rather rare, such as mats which are too soft for the type of traffic given, too hard so that they do not have proper impact resistance, or otherwise cause trouble without any of the previous reasons being assignable.

Better Failure Analysis and Classification Desirable

While these various failures are recognized in general and classified something along the lines given, the classifications by the various writers when carefully analyzed are not exactly the same. Furthermore, actual classification and systematic recording of the types of failures encountered is rarely made in regular maintenance work; it seeming generally felt that the individual responsible for the particular repair, a man well down in the organization if it is small, well up if it is large, is competent in each case to decide the source and set the remedy. Without inferring that this is not true, the Chairman wishes to raise the question whether systematic record keeping on such failures would not in the end assist in reducing the cost of maintenance; also whether the materials department, probably through such record keeping, might not be advantageously brought into the picture more definitely than is at present the case. Systematic analysis of all failures representing any considerable maintenance expenditure, and accessibility to such records by all interested, should in the end bring out much information not now available. It is true that at present the excessive cost of maintenance on jobs with poor bases almost completely overshadows any differences or savings that this would bring out. However, this mileage costing such excessive maintenance is, or should be, rapidly disappearing, and the benefits of systematic classification and attention to the other varieties of failure will then appear more worth while.

Correction of Failures

There is really more uniformity in the methods used to correct failures than there is in their classification. This is to be expected as the same means will correct several different causes, and from this standpoint the actual source may not matter. Possibly the greatest advantage of proper maintenance analysis will not be so much in maintenance work as in later construction based on intelligent design made possible by such information. Essentially there are three types of repairs, as previously listed. The differences between the practices in various states are more in the border line cases between these types of repairs than they are in the great bulk of the work.

Correction Methods

The first, most serious, and most expensive method of repair used is reconstruction. This may or may not include thickening and correction of the base, thickening of the mat, and change of binder in the mat. The trend is towards base correction at the time any serious reconstruction is done. The second method is the reworking of the mat to dry out, used almost entirely for moisture troubles. Any reworking usually involves the addition of bituminous material to offset for the new aggregate brought in and to make up for apparent loss in reworking. In the case of over-rich mats, or those assumed to be over-rich rather than showing moisture, aggregate rather than bituminous material may be added. The third general method of correction is by the use of a seal coat or increased layer on top of the mat. It appears that there should be a sharp distinction between these two treatments and in a few states such is the case. In others practically all treatments of this type result in an additional thickness to the mat, as cover is always added in case the job is surface treated with bituminous material even if such an operation is described as seal coating. As was brought out in discussion at the Conference last year, and in the Maintenance Section outline, there should really be careful differentiation between seal coating where no cover is used and armor coating where cover is used and additional thickness of mat results. The true seal coating operation is suitable for strengthening the upper surface of the mat, preventing raveling and sealing off moisture from above. Some very apt remarks on the necessity of these operations are made in the various papers, and the importance of seal coating is apparently becoming to be thoroughly appreciated in the majority of states in this territory. Armor coating treatments, or additional thicknesses of mat, are the alternate to this construction. They may be used for the same purpose, or additional ones, primarily the building up of the mat thickness as part of stage construction, or because it is realized that the mat is probably too thin and the most advantageous repair is to at the same time to increase its thickness.

Choice of Methods

As before stated, the differences appearing in the papers in the use of these fundamental repair methods is primarily in the choice of application. All states agree that where the job will unquestionably fail due to the base, either from poor drainage or insufficient foundation course or both, reworking and stabilization or strengthening the foundation is essential. Some take the attitude that this must be done regardless of the degree of failure. Others utilize the old base and mat, which have failed either due to inadequacy of the structure as a whole or to some unit, and provide sufficient further strength by a surface treatment course sufficient to satisfactorily handle the traffic. This is of course only done where observation indicates a moderate increase in thickness is all that is needed.

There seems to be little difference of opinion as to the need of reworking for moisture correction, and no alternate choice. Very little seems said about increasing the film strength of the binder in the course of this reworking, but this seems a desirable operation. The other point of difference between the various practices is in the type of seal coating used, as indicated by the description of the differences in the two methods given this name. This seems properly a matter of correct understanding, with each state making the decision on the basis of individual conditions, but seal coating seems to be one of the subjects which would benefit from full discussion by the Conference.

Special Maintenance Methods and Materials

While special application of special maintenance methods and materials, as distinguished from those generally developed and applied to construction, was emphasized in the original outline for the section, there were only a few comments on such practices. Actually it seems to the Chairman that there has already been much application of special materials and methods, but that those are not realized as being such. For example, even those states still using slow curing oils for mat work will change to the medium curing or rapid curing type in their repair work, which from the standpoint of strict logic is the application of a special maintenance material compared to the original construction job. In the same way there are probably many special bituminous practices differing from construction which are not thought of as such and not described. This subject appears to have a fruitful field for both discussion by the Conference and ultimate development by the various maintenance departments. Those papers discussing special maintenance materials in almost all cases report considerable benefit from their use. In other words, the application of rational engineering analysis to maintenance problems, and the development of different methods or materials for such problems, seems justified, and may result in definite improvement over the treatment of maintenance as simply the further application of construction methods to the job after it is originally built.

Trend of Maintenance Practices

The concluding subject of the maintenance outline is the trend of bituminous practices in the district. This seems to have been difficult for some of the individual writers to answer, and is an even harder question for the Chairman to cover except in certain indirect respects. The most noticeable trend in maintenance practices is their definite development as such. In other words, these papers bring out that the subject of maintenance is being given careful attention, opinions are being formed, and the whole subject is receiving careful consideration. The majority of the states now realize that the construction of bituminous surfaces is merely the first step and that careful, definite and well-planned maintenance is an inherent part of the work. Another trend is that this definite development and control of maintenance is resulting in uniform and quite reasonable maintenance costs for such surfaces. Those building bituminous roads can now be assured that the construction and annual upkeep cost, the total cost to date, or the amortized first cost of the job and its maintenance, depending upon the point of view desired, are extremely reasonable compared to any other type of surface, and apparently in most cases the cheapest that can be built. In other words, the showings on cost in the various papers indicate that we can definitely assure ourselves as engineers that we can build jobs that will show reasonable ultimate costs if we properly control the design features in their construction.

Another possible trend is the leaning towards heavier mats by those states which started out with very thin mats, and the development of thinner mats by those which started out with heavier construction. These trends may be summed up by saying that there is a definite development in design to suit individual conditions, getting away from arbitrary standards of construction regardless of the conditions encountered. All these trends are distinctly beneficial and if to them we can only add, as result of these papers, this Conference, and other such activities of highway departments, a trend towards careful analysis of the conditions and logical solution of them from an engineering standpoint, we can say that bituminous construction has passed from the experimental stage into a definitely established branch of engineering. We can say at the same time that the contributors to the development of this type of surface have given the road traveling public one of the greatest means towards the wider enjoyment of all year 'round transportation at costs within the reach of all, and that they have made possible the removal of roads from the luxury into the necessity class just as the modern maker of automobiles has converted these machines into an absolute necessity instead of a convenient luxury.

DISCUSSION ON MAINTENANCE OF BITUMINOUS SURFACES

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EMIL H. SCHULZ,
County Surveyor, Ramsey County, St. Paul, Minnesota

Mr. Nevitt: It is my suggestion that we first discuss the administrative side of maintenance and then get into the engineering side, as the bulk of the discussion will probably be on the latter. We will first open discussion on the administrative phases of maintenance.

The first point I have marked in my general outline is on maintenance organizations. There are two types advocated, the patrol and the crew, though there is not so much difference in the conditions under which they operate, as both are supposed to keep a year 'round watch of the roads in their care.

Anybody want to raise any point on that?

This question of maintenance control in records is clearly out of my ability to form much of an opinion personally, except second-hand. I will throw it open for discussion, whether or not we can profit from a more systematic classification of these records. In the administering of anything like maintenance, you have things repeating themselves. In such cases you generally benefit by some kind of a statistical record, but I cannot pick out of the papers a systematic tendency to keep records. It is either being done as a matter of course, or in some places there is nothing being done.

Mr. Perry, do you feel that in maintenance work, the maintenance system we have today, not merely those under discussion, could be improved in systematic record keeping on failures?

Mr. Perry:
Iowa

I think possibly we could. Certainly we are interested in knowing what these different parts of our bituminous maintenance are really costing. A lump sum means nothing. Comparable detail costs are necessary in order to know what you are talking about. When we say Montana's maintenance, for instance, is $200 per mile, Washington and Oregon might be $400 and Iowa might be $800. Such costs do not mean a thing unless you know what you are talking about. We certainly must come to some basis where we can compare and know what we are comparing.

Mr. Nevitt: Is there any discussion on that from the floor?

Mr. Houk: Alabama

Maintenance cost data is very misleading and very uncertain because it is my observation that the maintenance cost on bituminous surfaces throughout the country has been increased to an extraordinary degree by faulty construction, and much of the expense included in maintenance charges is not properly chargeable to maintenance. Some of the states are continuing to go ahead and throw maintenance funds into the temporary corrections of construction faults. In a good many cases they are doing this because they do not realize that they cannot correct these construction faults by proceeding to apply a light retreatment which hides the fault and only temporarily maintains the surface. I have in mind one state which had very heavy frost damage last spring and has spent several hundred thousand dollars in applying retreatments and seals and other temporary measures under the guise of maintenance. It is certainly not economical construction or maintenance to so attempt to correct defective subgrade and defective base courses. It takes a lot of courage to tear up a failure and reconstruct it, and it takes a great deal of judgment to decide when to reconstruct and when to attempt to build up or correct, so it seems to me—as the gentleman said—we must know what we are talking about when we speak of comparative maintenance costs. We must distinguish between the defects of design and defects of construction and relative maintenance. I don't believe defective subgrades and base courses can be corrected by temporary measures or thickening treatments or wearing surfaces, so unless you actually know what the maintenance cost includes from personal knowledge of the particular road, it is very difficult to come to any intelligent understanding of the true cost of maintenance.

Mr. Nevitt: Mr. Houk, could that situation be corrected in addition to cost records by some sort of record control on the repair work done, showing the type of maintenance given; that is, whether it was really a repair, or a correction of fundamental faults in construction?

Mr. Houk:
Alabama

It would be a rather difficult proposition.

Mr. Nevitt: As I understand the situation today, there is very little record keeping that is being done other than just the cost; no analysis to correlate those costs with the mile of work that went bad, on account of bad grade, insufficient oil, etc.

Mr. Vail:
Colorado

I am wondering if the whole thing is not a correction matter, or in other words, how would you discuss maintenance of an oiled road? In our class of construction work in Colorado, for instance, we are handling all of our oil work through the maintenance department. In addition to that, we have regular oil processing projects taken under the construction department. Coming right down to it, aren't the corrections made immediately afterward, like corrections in the base, corrections in the mat, etc. In other words, the maintenance of an oiled road if properly laid is practically nil, with exceptions of shoulders. At the present time nearly all the faults are of construction. Maintenance is betterment in nearly all cases.

Mr. Root:
Iowa

About fifteen years ago John Donaghy, maintenance engineer of Wisconsin, defined maintenance and I feel that his definition fills the bill as well as any I have heard. This definition was later adopted by the Mississippi Valley Association of State Highway Officials and also the American Association of State Highway Officials. I don't know that I can give the exact wording of Donaghy's definition, but it was substantially this: "Maintenance is that work necessary to hold a road in the condition in which it was left by the construction forces, excluding from that cost any expenditure for increasing the thickness, or the widening of the road, or for changing the type to a higher classification."

I think that it is important for us to make this differentiation between maintenance and betterments. I agree with Mr. Vail that in a way all maintenance expenditures are correcting mistakes of the construction department. I might go further and say that maintenance also corrects mistakes by the design department. I think I can illustrate that in this way: If the design department designs a road 18 feet wide and after the road is put into service we find that the width is insufficient and we have to go in and with maintenance money widen the road to 24 feet. That correction of the design department, while being paid from maintenance funds, should not be charged as maintenance but as a betterment.

If the construction department allows the wrong kind of material to be used in a bituminous mat and we have to go in and tear up and rebuild it we are correcting a mistake of the construction department and such expenditure should be charged to maintenance inasmuch as we are simply bringing the road back to the condition in which it was left by the construction department.

In Iowa we have to expend large sums of money from the maintenance fund for frost boil treatment. We try to take care of these frost boils when the road is constructed, but in spite of this we find many of our black top roads breaking up over wet cuts. We have to remove the mat, dig out the material and backfill with crushed rock. Expenditures for such work are charged to betterments rather than maintenance.

Mr. Nevitt: This is a very interesting discussion, and as I read through the papers some states make this distinction. It is very difficult to compare costs between states for this reason.

In further connection with this question of the road itself, in following my outline, the materials department is called in when the maintenance department thinks they should be. There is cooperation but no systematic handling of that point. I don't know whether this is the best way to handle it, or whether or not the materials department should be brought into the picture definitely in this sort of work. That is a good topic for discussion.

Are there any materials men here?

Mr. Duff:
Nebraska

Mr. Chairman, I should like to say just a word or two about maintenance costs and their relation to construction costs. I agree with Mr. Houk that maintenance cost data is very misleading and that a great deal of the maintenance cost is occasioned by faulty construction or perhaps it would be more proper to say faulty design. This tendency toward faulty or inadequate design is not necessarily due to a lack of knowledge on the part of the state but rather a desire on the part of some states, in fact most states, to show a large construction mileage. Usually the states have a certain amount of money set up for construction and in order to get a large construction mileage they try to reduce the cost of construction at the expense of maintenance.

If an accurate cost account was kept of both construction and maintenance over a period of years we would be able to compare the advantage of better initial construction. A cost system which would show at any time the actual total investment in a road based on the cost per square yard, per inch of depth, would give an accurate means for comparing costs. It would then be possible to definitely determine the advantage or disadvantage of increased thickness of mat, adequate stabilization of the base prior to mat construction, type of road oil used, and many other items whose value is questioned. In other words, you have definite information as to whether it was less economical to build a cheap road which would require a great amount of maintenance or to build a road that has a higher first cost but which was constructed on an adequate base and has been properly designed.

If such records were kept it would be possible to determine at the end of 5, 6, 7 or 10 years just what each road was costing per year, per square yard, per inch of depth, which I think is the only fair way to make comparisons. This cost at the end of the first year would be high, but it would be reduced from year to year and over a long period of time might reach a figure as low as 10 cents per year, per square yard, per inch of depth, and would undoubtedly give a good comparison between cheap construction followed by high maintenance and high type construction followed by low maintenance.

Mr. Nevitt: Undoubtedly that could be done and I have great hope that the papers today will show what is badly needed in this respect, so that more data will be available next year.

Is there any further discussion on this point?

Maintenance costs are part of this whole problem. The proper type roads to originally construct can in the end not be determined until we have a complete maintenance record by which to judge them.

Mr. Saville:
Missouri

In writing specifications in our state, we frequently refer to the practice in other states, and the information which we obtain is of little value unless expressed in terms of effort and procedure in maintenance.

I am inclined to agree with Mr. Root in the manner in which maintenance should be expressed. It does not appear feasible to allow in design for all the possible conditions that might come up. For example, Mr. Groves of North Dakota reports that last June they had some trouble with surface failures and discovered that frost boils extended to a depth of 12 feet. Protection against such conditions would be considered over-design and generally beyond our financial resources. In design we have to discount some of the things we now are recommending in maintenance. Whether a portion of the work done under maintenance should be changed to maintenance is very doubtful. Mr. Root's idea of differentiating between maintenance and permanent improvement to the road is a very good one. The maintenance operation should be listed in terms of what is done and not in terms of cost. In other words, we believe that there should be a record of type of work instead of cost data.

Mr. Sweeney: Minnesota

Mr. Schulz, our county engineer, introduced a system of costs records very similar to that which the railroads have for making reports to the railroad commission. We carry out the same thing on both maintenance and construction of our bituminous roads and I believe it is a good idea to have an account number for each and every phase of the work, and if this is done it is possible to, at any time, determine just what has been done and what the exact costs of the different phases have been.

Mr. Schulz: Minnesota

For example, in connection with the costs we have on frost boils we consider those additional to the problem of maintenance. A complete record makes the property worth that much more and annually we make a report to the county auditor showing how much we have increased the value of the property.

Mr. Nevitt: Storage tanks, etc., are the next topics. Any discussion?

Winter maintenance is also a point that came up. There is a marked trend toward more winter bituminous maintenance. Anybody want to ask any questions or discuss that?

The effect of traffic on bituminous maintenance construction was brought out in some of the papers. That is one thing I think should bring up a lot of discussion.

Mr. Hart:
Montana

There are two points that I think could be discussed to advantage in that connection at this time. The first deals with practice of the various states with reference to the use of the traffic stripe upon those roads that do not carry particularly heavy traffic, and the second is the matter of temporary load limit restrictions which are imposed during the spring of the year, and during other storm periods when the oiled mats are subjected to damage from heavy loads.

We find considerable difference in traffic stripe practice. In Montana, for example, we started out to traffic stripe all of our oiled highways. It was our experience upon those sections which were of light construction, without adequate metal in the base, that the edges of the oiled mat are being broken down by heavy traffic which was held by the traffic stripe to the shoulder or side of the roadway. In order to protect the oiled mat we discontinued the traffic striping of those roads that do not carry a heavy volume of traffic.

Mr. Nevitt: The center stripe is a common practice. How about them in your country, Mr. Draper?

Mr. Draper:
Mississippi

We use the center stripe.

Mr. Nevitt: Up north they seem to object. What is your opinion, Mr. Perry?

Mr. Perry:
Iowa

We have not marked any center lines in recent years.

Mr. Smith:
Wyoming

In Wyoming we use the center stripe on vertical and horizontal curves only, except that in some places along the Lincoln Highway where ground blizzards are extremely bad during the winter months, we use a dashed stripe on the tangents or straight-aways and a solid stripe on the horizontal and vertical curves.

Previous to this year we used an orange paint bought from various companies. In striping our roads this year we are using a paint formula developed in our own laboratory that has proven very satisfactory. It is a quick drying yellow paint. We prefer to use either the orange or yellow stripe due to the fact that it is of considerable aid to the traveling public during bad snow storms and ground blizzards.

Mr. Newland:
Washington

In Washington we stripe nearly all surfaces except thin oil mats of limited anticipated life. We use yellow traffic line paint, the application of which costs about $25 per mile. We do not make a practice of using the dash system inasmuch as the saving effected is less than 50 per cent of the cost of material, the labor cost being approximately the same.

Oregon uses white on concrete and yellow on bituminous surfaces. Nearly all surfaces are striped. The machine used, similar to the one used by Washington, is the small application machine pushed ahead of a truck, the compressor and paint tank being carried on the truck chassis.

Mr. Draper:
Mississippi

Our maintenance engineer developed a new theory and a new machine. This machine applies a spray of about 150 penetration hot asphalt and covers it with ⅜-inch chips. This creates a raised center stripe about six inches wide, which is plainly felt when one drives across it. His thought is that when a person absent-mindedly drives over on to the center he feels the center stripe, whether he sees it or not, so that he can know to pull back to his lane. It almost created a young revolution at first, because it did give light cars at high speed a slightly uncomfortable side sway. As time goes on, he thinks that it has become more popular, and is continuing to apply it. It seems that it will last indefinitely, since we have some that is three years old, still in good condition.

Mr. Houk: Alabama

We drove over in Mississippi and heard the comment about this line. Some people didn't like it. We crossed over the center of the road too much and we found that out when we got up in Montana. I really believe this is a revolutionary design that Mississippi has developed. They use a yellow chip or yellow gravel and the traffic line is a layer of chips, and the lasting quality is superior to paint.

Mr. Draper: Mississippi

An old Model A Ford truck was used as a chassis for the machine. It carries a heating kettle, mounted where the truck engine formerly rested, a rotary broom for cleaning the surface, and a pressure pump, both geared to the old drive shaft of the truck, a one-half cubic yard bin for the chips, with a chain conveyor for feeding the chips sidewise to a chute centered over the hot asphalt, and a wide band on the left rear wheel tires to act as a roller. The entire assembly occupies the right half of the pavement, pulled by another truck, which also carries a load of chips. The striping operation is performed altogether along the line of the left wheels of the old truck, the steering being controlled by an operator sitting directly over the center line of the road. The machine was assembled in our shops at Jackson, and needs perfecting but it is capable of striping as high as 40 miles per day if the asphalt and chips are kept on hand to keep it operating steadily.

The stripe has been built with a wide variety of bitumen and also various types of aggregate, including oyster shells, slag, pea gravel and crushed gravel of various colors, yet there does not seem to be a great deal of difference as to the effectiveness of any of them. The slag, on a black road, gives a pleasing contrast and apparently will never wear out. The cover material is applied at a rate of about 30 pounds per square yard, or about four and a half tons per mile, and the bitumen at about .3 gallon per square yard, or 90 gallons per mile. The crew consists of an operator, a truck driver and about two helpers.

Mr. Nevitt: On the topic of maintenance, seal coating should require some discussion. In the papers we had a difference of opinion as to the amount that should be done; types, quantities, and the use of special materials in seal coating were brought out in some of the papers. Seal coat should be a very fruitful topic for discussion with the differences of opinion or conditions which are definitely brought out.

Do we have any comment or questions on seal coat? I have some slides of typical conditions and if you are interested I would be glad to show them.

Mr. Black:
Oklahoma

Mr. Nevitt, in your paper, do you mean that in some sections seal coat is used without cover material, without chips or other non-skid material? If so, what type of asphalt do you use?

Mr. Nevitt: Seal coating without cover is being done quite extensively in Montana and Wyoming. Maybe not entirely without, but using only negligible amounts of cover. Iowa also does this. Perhaps it would be a good idea for me to run my slides on this to start discussion.

Mr. Black:
Oklahoma

What are the specifications on the seal coat material?

Mr. Nevitt:

I will ask Mr. Mason of Montana to answer that question as he is familiar with that type of work.

Mr. Mason:
Montana

To begin with, we were given the specifications for RC-1 several years ago at a meeting in Salt Lake City. This specification called for a penetration of 60-120 on the residue. On trying this seal we did not think it dried rapidly enough and believed it could be improved by using a more volatile cutback. Wyoming, I believe, was the first state in the northwest conference to deviate from the regular RC-1, or the so-called "old RC-1." I think they used a base asphalt hard enough to give a residue of 60-80 penetration.

Mr. Nevitt developed a seal using a much harder base asphalt and giving a residue of 20-40 penetration. We used this with good success but were afraid it required too hard an asphalt for our cold weather conditions. We then developed a seal having a penetration of 50-80 on residue, which, of course, gave us three different types to choose from. Each of these seals varying a little as to the penetration of the residue and as to the percentages off at the various distillation temperatures.

Mr. McCoy:
B. P. R.

I think your last drawing showed the results we want but it looked like theory. It is a very good type of seal and is used a great deal in the West, but does it actually produce the results you picture? I have noted a tendency for the asphalt to hang on top. Does it actually penetrate to the depth you show and in fact fill the interstices?

Mr. Perry:
Iowa

I can't tell you what the penetration is. There is a tendency to hang to the top or sealing, developed on top of the aggregate.

Mr. Draper:
Mississippi

I don't want to tell you too much about Mississippi, but our observations are just backward to what you seem to indicate. Our theory is that our asphalts have been entirely too heavy in all construction. Now here is proof of that. Thirty days ago we had the refinery make us up a cutback from about 325 penetration asphalt with just enough 400 end point naphtha to give us about 150 viscosity (Furol). Then we told the gravel plant to ship two cars of concrete sand with which to cover the shot on a road mix project built last year. To my surprise, we found the plant had sent us pea gravel, with nothing smaller than 8-mesh with ½-inch average sized round slick and dripping wet, but since we had the department's double crew, material, asphalt and gravel on hand we decided to try it. No one yet who has seen it can say anything in criticism of it. We didn't lose any of these pebbles.

Mr. Nevitt: There is a difference of opinion as to what material should be used for this type of sealing. Hanging up depends on the job. We seem to have a difference of opinion in the papers, indicating some states believe that this type of maintenance will do in many cases. Other states, like Mr. Draper's, don't ever do this.

First, we will hear from the states that do not believe in this type of maintenance.

Dr. Loy:
Wyoming

I should like to ask the gentleman from Mississippi whether he has determined upon the best temperature at which 325 penetration should be applied.

Mr. Draper:
Mississippi

It makes no particular difference, but I would say about 140 degrees F.

Dr. Loy:
Wyoming

That seems very low.

Mr. Draper
Mississippi

Well, you cannot heat much hotter than that on account of the naphtha. I think the temperature would not have a great deal to do with it. However, I would not attempt to do this work in freezing weather. We made no attempt to let the pea gravel dry out. We carried traffic on one-half of the road while we treated the other half.

Mr. Saville:
Missouri

Our state has employed several different types of seal coats, most of which have given the results for which they were intended. The question comes to my mind, which is purely theoretical, regarding the relative merit of the sealing processes illustrated by Mr. Nevitt in his discussion. If a pavement were sealed with a light cutback by penetration into the surface in amounts sufficient to close the voids, there would appear to be doubt in having the voids adequately sealed.

A sealing process which would place a thick film of the bituminous material over the surface of the existing pavement and then sufficient metal of proper gradation to protude above the surface of the bituminous film appears more positive in its results. This treatment would provide friction for traffic and theoretically at least a more positive seal.

Mr. Nevitt:

We have a lot of representatives here from the State of Wyoming. They do both types of sealing, and I think it would be helpful if Wyoming would tell us why they use both types.

Mr. Smith:
Wyoming

Our state is different from most of the states in that we have limited funds for maintenance. The type of seal coat used is dependent on two things. First the amount of funds available, and second the type of road to be sealed.

A well constructed road consists of three layers, the grade itself, the base and the top course or wearing surface. In Wyoming we have limited our stone chip seals to jobs where all of these laysers are in first-class condition. We agree with Mr. McCoy's statement that seal wears off, but due to lack of funds we have been forced to use the so-called paint seal in the majority of cases. During the past three years we have included a paint seal in all contracts. By so doing we are able to get our oiled roads sealed out of federal aid funds, thereby saving our state funds for other work.

We have found that in general a seal coat of RC-1 or RC-2 cutback does not make an oil road slick. However, there are particular cases along short stretches of road that have been made slick due to using too heavy a seal of RC-2 on an oiled mat constructed of a dense grade of aggregate.

Mr. Draper: Mississippi — Most of our slick roads are where they have been oversealed with too fine a sand. The seal I described cost us about four cents per square yard.

Mr. Nevitt: Mr. Smith, have you anything to add?

Mr. Smith: Wyoming — I do not believe so, except that the ordinary paint seal used in Wyoming cost about one cent per square yard. The main reason that the paint seal is used so extensively in Wyoming is that in the early days of the oil road in order to get Wyoming out of the dust we built considerable mileage of thin mats on roads with very little base. We have found that we have considerable failures both in the subgrade and base on these thin mats and do not feel justified in placing an expensive stone chip seal on these roads due to the fact that, even with this high type seal, we would still have a lot of scarifying and reprocessing each year to do due to subgrade and base failures. We have found that by keeping these roads sealed with an RC-1 cutback that the life is extended several years.

Mr. Nevitt: I might say to Mr. Saville's question that I have a slide which goes into that, but it isn't possible to take the time to show it now. However, I will be glad to run it later if anyone is interested.

Mr. Archibald: Nolan Bros. Minnesota

The majority of our oiling contracts with the Montana Highway Department in the past three years have required seal coat oiling with RC-1 naphtha cutback asphalt. Almost invariably the specifications have designated application at the rate of one-tenth gallon per square yard, which from my observation is insufficient to assure complete coverage or sealing. We have experimented with varying amounts, even applying as much as one-half gallon per square yard, and reached the conclusion that approximately one-quarter gallon per square yard has given the most satisfactory result. Of course, the amount required will necessarily vary with the density of the surface, this being dependent upon the gradation of the aggregate used in the mix.

Upon completion of sealing one particular section, after applying approximately the specified amount of one-tenth gallon per square yard, investigation showed that incomplete covering or "hanging-up" was prevalent, so on the recommendation of the engineer in charge of the job we superimposed an additional one-tenth gallon per square yard of RC-1 on the same section. We observed that the drying period of the second application was approximately double that of the first, probably due to a very small percentage of the second coat being absorbed into the mat and most of the drying taking place by evaporation. The experiment was justified for the coverage was thorough and the surface made impervious to water. Depth tests showed a penetration of one-quarter to one-half inch of RC-1.

Mr. Nevitt: I can add to that several things which have to be watched and Mr. Archibald's comments are very pertinent. If you use too little in this or anything else, you get such a rapidly drying product that you get hanging-up, but if you use enough you will get penetration of ¼ to ½ inch.

Any further comment?

Dr. Loy:
Wyoming

It may enlighten those of you who do not use it to know that the specifications of regular RC-1 and the RC-1 of Montana are different. Montana's viscosity is at 77 and the regular RC-1 viscosity is at 122. A difference in naphtha of almost 50 per cent more accounts for the facts brought out relative to getting coverage.

Mr. Nevitt:

Iowa RC-0 represents material of the same type having a varying viscosity at different temperatures. I don't want to go into them unless the conference desires to spend the time.

Mr. Draper:
Mississippi

We like a quicker curing, high power naphtha in preference to a hard base.

Mr. Nevitt:

Do you suppose you could get lighter naphthas? It has not been tried. The I. C. C. regulations call for 80° flash, which has generally set the lower limit for the naphtha used in our territory.

Mr. Draper:
Mississippi

We go as low as 400 end point. You get all the toughness you need. If this does not cure out fast enough, blot out with a little sand or waste chips.

Mr. Nevitt:

You were talking about drying.

Mr. Draper:
Mississippi

This is 400 point. There are lighter naphthas, but I think the flash points would be too low to comply with I. C. C. regulations, if enough material is used to handle the material out of tank cars without heat.

Mr. Houk:
Alabama

It is very difficult to use hard asphalts in a base. My observation has been that we have been using entirely too hard a base

Mr. Nevitt:

Are you talking about the mat?

Mr. Houk:
Alabama

I am talking about anything you put on the top.

Mr. Draper:
Mississippi

Then you are going to have to use something to soften it.

Mr. McCoy:
B. P. R.

It might be interesting to call your attention to the fact that California has an entire series of liquid asphalts, ROMC grade, which are made by cutting back .95 road oil. This is about the same as a 200 penetration asphalt. There is a complete series running from ROMC-1 to ROMC-5, the last one containing about 13 per cent kerosene. This is used a great deal more in California than the standard grade MC.

Mr. Draper:
Mississippi

I did not mean to tell you that we knew more than others. About three years ago we built several miles of 4-inch hot asphaltic concrete with a penetration of 40-50. We are now getting serious cracks. I think we should go to 85-100 or lighter. Everything we have done in the South seems too hard. It is surprising how it has recently developed the other way, to softer bitumen.

Mr. Houk:
Alabama

Oxidation in these residues with time is one reason we hold to thin type with our bituminous surface, so that they can be easily rejuvenated by top application if and when they get too hard and brittle.

Mr. Nevitt:

In regards to this cracking Mr. Houk mentions. Mr. Smith, do Wyoming SC- mats crack?

Mr. Smith:
Wyoming

Yes, to some extent in extremely cold weather. I think we have cracks on very faulty material.

Mr. Nevitt:

Any more comments on this general question of seal coats, which has developed a lot of interesting things to me? We are getting along in time.

The next thing of general interest is a different question, in fact of fundamental interest to the maintenance section, and that is the engineering discussion of maintenance. As I explained in my paper, I believe the first thing is the proper analysis and determination of the cause of failure is badly needed. I would like a little clarification from that standpoint.

Mr. Draper:
Mississippi

In my observation, instead of building black top roads we have been building open top roads.

Mr. Nevitt:

That is the first one to stress the opposite side of the question. Any other discussion?

Mr. Duff:
Nebraska

I will agree that most of our bituminous surfaces are not waterproofed. However, I do not believe that our failures in general are due to open top construction, at least I think they are very few. The majority of our failures are caused by water entering the mat from the bottom rather than from the top. I think the principal cause of failure comes from the capillary action of water on the under side of the mat which softens the subgrade. In many cases this water enters the subgrade under the mat by lateral capillary action from the earth shoulders which do not properly drain into side ditches. When the subgrade under the mat is softened by water from any source it will yield under traffic loads, which naturally makes your top fail. Such failures are frequently found near the shoulder line, which strongly indicates that water has entered the subgrade from the shoulders.

Mr. Nevitt:

Do we not have more than one type of failure due to different road elements? These may not be serious, but do you feel that all failures are water failures; that is, due to water from below?

Mr. Duff:
Nebraska

No, not all failures are due to water, but it is one of the major causes. The type of asphaltic oil used is also a factor, and that brings us right back to the previous subject about the use of too hard an asphalt. I have felt for some time that more durable mats could be obtained by using cutback products produced from softer base asphalts. I believe that mats constructed with asphaltic products having a softer residue would be less likely to become hard and brittle and yet offer sufficient stability. What we need is a mat with lasting toughness and one that will deform rather than crack under slightly yielding bases. We may still have some oxidation with soft asphalt, but I do not believe the deterioration would be as rapid. We have used asphaltic oils meeting the same specifications from two different refineries and have found the mat constructed from one product was satisfactory while the mat in which the other product was used lacked toughness and the oil appeared to be inert and to have very little adhesive qualities. This difference in quality is probably due largely to the type of residue or base asphalt used. We get this type of failure on account of the broad limits permitted by the specifications of the Asphalt Institute.

Mr. Nevitt: Have you established any correlation between the hardness and of the softness? That is, between your troubles and your success?

Mr. Duff:
Nebraska

We have made a comparison between the homogeneous and highly cracked products, but not between the use of soft and hard base residues. Most of the cutback products used this year were supplied from two refineries and the penetration of the residue ranged from 120 to 150. No products have been obtained that have had a 200 to 300 penetration on the residue.

Dr. Loy:
Wyoming

Professor Duff's talk was very enlightening to me. He mentions getting their material from two refineries and it has always ranged from around 120-150 penetration. On the surface it would appear that Professor Duff's suggestion was well taken. Some states require a penetration from 100-200, other cases from 200-300.

These figures are based on what I have been able to get.

Mr. Duff: Nebraska — Practically all MC specifications permit the use of asphalt residues having a penetration range of 100-300. I would be in favor of dividing the range so that products could be obtained having a penetration range of either 100 to 200 or 200 to 300.

Mr. Nevitt: You will have to change your specifications to get 200-300 penetration residues from all producers.

Mr. Duff: Nebraska — We would specify this division, but we hesitate to deviate from the recommended specifications of the Asphalt Institute. I feel that some effort should be made to limit the number of products required and this would not follow if each state writes its own specification. There should at least be a trend toward Simplified Practice.

Is there any work being done or data available using exactly the same oil but with varying aggregates of different chemical composition; or any data available showing whether they adhere to the same type of oil, using light stone in one case, granite in another; would it affect wearing quality of the finished job?

Mr. Nevitt: There are too many variables to directly correlate the comparative success of various jobs with the types of stone in the case of usual gravels or stone.

Mr. Draper: Mississippi — We have discovered that Mississippi glacial gravel is highly hydrophilic, but that a little bit of naphtha added to the asphalt changes that entirely.

Mr. Nevitt: We still do not have the failures analyzed to the basic reason. Only one or two reasons have been mentioned. The various papers do not agree on causes. We surely should get a raise on that. I have not heard anything. Is everybody satisfied?

With respect to foundation trouble, we have had Professor Duff bring out that a loose, uncompacted base will cause rolling of the mat. This is not mentioned very much, being an uncommon trouble. He also brought in slippage between base and the mat. This is another interesting thing—it might be of concern to those of you who discussed priming as to whether such priming would have any effect on this trouble.

Mr. Duff: Nebraska — Will you ask some Montana or Wyoming representative to give their explanation for a surface type of failure which I observed on a few sections of their bituminous mats? Most of their oiled roads over which I have traveled had an excellent riding surface and were well constructed, but occasionally a section would have marked tendencies to pot-hole. Just what caused these pot-holes?

Mr. Hart: Montana — What was the nature of the pot-hole, was it a penetration job?

Mr. Duff: Nebraska — I cannot say as I did not stop and make a close examination. The edges of the holes presented a raveled appearance while the center portion of the hole appeared to extend several inches below the mat proper.

Mr. Hart: Montana — There are a number of older jobs where we have trouble with pitted conditions, or pot-holes. These jobs are not supported by adequate metal. They were penetration oiled, using an SC oil, and in many instances the cover material which was used contained earth instead of consisting entirely of clean sand or gravel.

I think that what happened in the cases you noticed were surface failures in the oiled mat due to the oil, on some of our older penetration jobs, being killed, or rendered inert in some instances through use of improper cover material.

Mr. Duff:
Nebraska

That probably answers the question for that type of construction. If you do not have adequate base metal a penetration job is little more than a dust palliative and cannot be expected to stand up. In Nebraska pot-holing is usually attributed to a lean mix or one in which the oil has lost its adhesive qualities.

Mr. Nevitt:

Are there any other comments on these surface failures? Water not troubling anybody? Have you any other types of failure that you would like to discuss?

I notice the papers have not come out on one particular matter, although some are quite actively interested. I am referring to the thickness of bituminous mats. Two trends are appearing; alternates of each other. Users of thin mats are trying thicker ones; those having used thick mats are also trying thinner mats. I particularly have in mind the Oklahoma paper. It reports a definite trend to thicker mats in stage construction, but simply to get a better acting mat. The feeling seems to be that the thin mat, starting with ¾-inch or 1-inch, is too thin to act as a unit.

Mr. Reid, will you give us your comments, if you are familiar with this point?

Mr. Reid:
Oklahoma

I do not know that I can tell you the actual reason for increasing the thickness as in some cases up to 3 inches, other than the intention to increase the stability of the unit for that type of work for use on some of the heavier travelled roads.

Mr. Nevitt:

Is all increased stability to be in the base? Can it be in the mat as well?

Mr. Reid:
Oklahoma

Much of this type work is placed directly on subgrade, serving both as base and surface course. Has supporting value as base and abrasive value as surface, yet it is all bituminous mat.

Mr. Nevitt:

Montana also reported a job where oil has gone bad due to oxidation, and they put a new mat on top of it, using that as a base. Anybody interested in asking Montana about that?

Mr. Draper:
Mississippi

We are repairing a concrete road that is being destroyed by heavy trucks and we are using 5 inches of asphaltic concrete.

Mr. Nevitt:

This seems to confirm the idea that you can get some strength out of a bituminous structure. We are getting right back to fundamentals.

Mr. Houx:
Alabama

What is the practice of those states represented here in repairing distintegrated concrete roads?

Mr. Nevitt:

A lot of the states represented do not have this type of road.

Mr. Saville, do you want to tell us?

Mr. Saville:
Missouri

I am not in a position to tell you the results we have had in resurfacing old concrete pavements in Missouri. Several methods have been employed but no final conclusions drawn relative to the merit of the several methods. Our work has been done principally on pavements which were very rough. In resurfacing we have used "second-story" concrete, dense graded hot asphaltic mixtures, open graded cutback and emulsion mixtures and various proprietary cold mixtures.

We recently had a concrete road fail under heavy loads and this is being reconstructed at this time by adding a width of two feet on each side, and on top of the old pavement is being placed approximately 4½ inches of hot mix.

Mr. Draper: Mississippi	We are not adding 5 inches on top; we are taking out the concrete and putting back an asphaltic concrete of special type. We will be glad to furnish details of this mix to anyone who might be interested. It is made in a small homemade plant with local materials.
Mr. Nevitt:	That is interesting. Anyone from the west coast?
Mr. Newland: Washington	We have not resurfaced any appreciable mileage of our concrete roads. In cities we have recently been resurfacing some old concrete with asphaltic plant mix. Some small mileage has been retopped with 5½ inches minimum of new concrete over the old. We have not as yet been faced with the necessity of reconditioning any appreciable amount of our concrete mileage.
Mr. Nevitt:	Any further discussion on that point? If not, the meeting stands adjourned.